**ENERGY IMPLICATIONS OF INTEGRATED
SOLID WASTE MANAGEMENT SYSTEMS**

Final Report

Prepared for

**THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY**

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An Energy Authority Report in Brief

Report: Energy Implications of Integrated Solid Waste Management Systems,
Report 94-11

Project Manager: Joseph R. Visalli

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Background: All methods of managing solid wastes use or produce energy. Energy is produced by combusting waste or landfill gas. Energy is used to collect, transport, process, compost, recycle, and dispose of wastes. Recycling also saves the energy of manufacturing using virgin materials. Because materials manufacturing using recycled or virgin feedstocks are global businesses, the geographic location where the energy is used and saved will vary. In general, the manufacturing location will be distant from where the waste is generated, and consequently there will be major energy impacts far from the area where the waste was generated. The type of fuels used to manufacture virgin and recycled materials will also vary. The energy implications of integrated waste management systems in large metropolitan areas like New York City are felt nationally and globally due to exported recycled materials.

Objectives: The project had four objectives: (1) provide estimates of the energy used, produced or saved by to collect, transport, process, dispose, recycle, compost and combust solid wastes generated in NYC using integrated systems outlined in the NYC Solid Waste Master Plan; (2) refine estimates of energy use in virgin and recycled materials manufacturing for 12 materials including iron/steel, aluminum, glass, four types of paper products, three types of plastics, aggregate for road base, and oil; (3) develop a methodology to determine where geographically the energy use and saving for virgin and recycled materials manufacturing will occur; (4) develop new software to model the net energy implications of integrated waste management systems.

R & D Results: Major findings were: (1) collecting and transporting wastes accounts for a small and negligible fraction of total energy use; (2) Processing and combusting wastes, and the energy saved by manufacturing using recycled versus virgin materials account for nearly all of the net 40-50 TBtus of energy resulting from managing the NYC waste stream each year; (3) Combusting waste produces the greatest individual net energy benefit; however, fully integrated systems provide the greatest net energy benefit when managing the whole waste stream; (4) recycling saves energy in almost all cases, but in some cases, such as producing writing and printing paper from recycled paper, more fossil fuels are required to recycle because the virgin process uses process wastes like tree bark for fuel; (5) although the individual tonnage of the 12 recyclable materials can vary by an order of magnitude (factor of 10) and the energy saved per ton of specific recycled materials varies by one-two orders of magnitude, the total energy saved for each of the recyclable materials varies by only a factor of 1-5; (6) combusting recyclable materials such as paper and plastics conserves about the same amount of fossil fuel per ton of waste burned as does recycling these materials (about $6-10 \times 10^6$ BTU/per ton of waste processed); (7) energy data regarding manufacturing recycled plastics were the most difficult to obtain and are the least reliable; (8) for fully integrated scenarios (using all methods of waste management), the energy implications of managing solid waste in New York City were: net energy is produced within the City due to waste combustion; net energy is used in the remainder of New York State due to increased manufacturing using recycled material; net energy is saved in the United States excluding NYS due to decreased manufacturing using virgin materials, and net energy is used outside of the US due to increased manufacturing using exported recycled materials.

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ABSTRACT

This study develops estimates of energy use and recovery from managing municipal solid waste (MSW) under various collection, processing, and disposal scenarios. We estimate use and recovery -- or energy balance -- resulting from MSW management activities such as waste collection, transport, processing, and disposal, as well as indirect use and recovery linked to secondary materials manufacturing using recycled materials. In our analysis, secondary materials manufacturing displaces virgin materials manufacturing for 13 representative products. Energy implications are expressed as coefficients that measure the net energy saving (or use) of displacing products made from virgin versus recycled materials. Using data developed for the *1992 New York City Master Plan* as a starting point, we apply our method to an analysis of various collection systems and 30 types of facilities to illustrate how energy balances shift as management systems are modified. In sum, all four scenarios show a positive energy balance indicating the energy and advantage of integrated systems versus reliance on one or few technology options. That is, energy produced or saved exceeds the energy used to operate the solid waste system. The largest energy use impacts are attributable to processing, including materials separation and composting. Collection and transportation energy are relatively minor contributors. The largest two contributors to net energy savings are waste combustion and energy saved by processing recycled versus virgin materials. An accompanying spatial analysis methodology allocates energy use and recovery to New York City, New York State outside the city, the U.S., and outside the U.S. Our analytical approach is embodied in a spreadsheet model that can be used by energy and solid waste analysts to estimate impacts of management scenarios at the state and substate level.

Key words: solid waste, energy balance, life-cycle analysis

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The findings, opinions, and conclusions of this study do not necessarily represent those of the Advisory Group or the Energy Authority, and any errors of omission or commission are the sole responsibility of the authors.

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SUMMARY

Our objective in this study is to develop and apply an integrated methodology for assessing the energy implications of alternative solid waste management systems inclusive of the direct solid waste management system effects and the second-order manufacturing impacts. Two principal audiences are, first, the New York State and other state energy offices charged with long-range planning and, second, county and municipal solid waste managers interested in estimating the energy requirements and costs of local solid waste master plans.

Traditional, single-facility municipal solid waste (MSW) management practices are gradually giving way to more complex systems emphasizing integrated, multi-facility approaches designed to divert waste from landfills to re-use and recycling, composting, and combustion with energy recovery. In New York State, as in most of the U.S., this transition has been spurred by the closing and cost of existing landfills, difficulty in siting new facilities, and an awareness of the resource and environmental benefits of using recovered wastes in secondary materials manufacturing and as a fuel for energy production.

One result of this transition is a change in the way energy is used and recovered at each stage of the waste management process: collection of waste from generators, transport of waste between management facilities, processing of recyclables, compostables and combustibles, burying waste, and energy recovery from waste combustors and landfill gas. Each change in the configuration of a management system triggers a change in energy use and recovery.

Energy use is affected by changes in the number, type, and size of collection vehicles; their fuel efficiency; and the configuration of the collection routes as new recycling and compost collection systems are put in place. Distances to processing and disposal facilities change as new facilities are added, as local facilities replace regional facilities, and vice versa. And energy use and recovery at the facilities varies greatly for each system configuration according to the number and types of facilities used for processing and disposal.

Beyond these direct effects within the solid waste management system, the use of recovered materials (recyclables) as feedstocks in manufacturing activities triggers second-order effects by both increasing product manufacturing from recyclable material and displacing virgin material-based production. These effects carry their own set of energy implications. When paper, plastic, aluminum, and ferrous products made from recovered materials displace those made from virgin raw materials, a chain of impacts in the virgin manufacturing system is created. These impacts begin with virgin raw material extraction, and continue on through raw material transport, intermediate, and final production activities.

Though secondary materials manufacturing at first glance appears to be more energy efficient per unit of product output than virgin manufacturing, a closer look reveals a more complex situation requiring an integrated analysis before drawing conclusions. Questions of *what type*, *how much*, as well as *where*, energy is used in virgin and secondary manufacturing systems are three dimensions of interest to energy planners and waste managers.

To quantify the energy impacts of the solid waste management system we identified all waste collection, transport, processing, and disposal activities where energy use and recovery occurs. This is the foundation for the first of two elements in the overall system analysis. Using New York City as a case study, we applied this framework to four scenarios containing various mixes of collection systems and facilities to compute an energy balance for each solid waste management scenario. The management of special waste streams such as sludge, construction, and demolition wastes, and harbor dredge were treated identically for each of four scenarios. Scenario C is most recycling-intensive with no combustion, while Scenario D is the most combustion-intensive. Scenarios A and B fall in between these two extremes. Table S-1 provides a breakdown of the energy associated with managing these wastes, organized by component of the management process. Appearing separately and treated identically across all scenarios is wood waste combustion, a distinct waste stream whose energy balance is handled in Section 4.

The various solid waste management scenarios result in the recovery of recyclables from the waste stream; this is the foundation for the second major element of the overall system analysis. Table S-2 lists the 13 materials diverted from the waste stream and the quantity recovered in each scenario. The total quantity of recovered materials is roughly the same for Scenarios A, B, and C, with the quantity for Scenario D about two-thirds that of the others. This latter figure reflects the combustion-intensive configuration of Scenario D.

Determining the energy impacts of introducing these recyclables into the manufacturing sector required the quantification of two production pathways for each material: production from virgin materials and the same process using largely, or exclusively, recycled materials. All energy uses in the production cycle are tracked up to the point where virgin and recycle manufacturing processes converge. We make certain assumptions regarding how far from the principal production pathways - extraction, transport, intermediate processing, final processing -- energy impacts are tracked. From this analysis emerges an energy coefficient representing the difference, expressed in MMBtus (million of 10^6 Btus) per ton of waste handled, in virgin versus recycle manufacturing energy requirements (Table S-3). These requirements show the difference between manufacturing a product/intermediate product from virgin raw materials versus recyclables where the following system components are included:

Virgin System Energy Components

Raw material extraction and processing

Product/intermediate production process

Transport of raw/intermediate materials to production process

Recycled System Energy Components

Recyclables collection, processing, and transport of residue from processing facility to disposal facility (i.e., recyclables acquisition energy)

Product/intermediate production process

Transport of recyclables/intermediates to production process

With the exception of aggregate materials for road base, all other materials show that energy is saved by using recycled instead of virgin materials. In all cases, the energy used to transport materials is far less than the energy used in the production process. However, the energy required to transport virgin materials for plastics (petroleum) and for aluminum (bauxite) is substantial relative to other materials owing to the location of principal extraction locations in foreign countries.

Energy coefficients without the recyclables acquisition energy also are calculated for synthesis with the New York City scenario-specific solid waste management energy calculations, to avoid double counting of solid waste management impacts.

We combined the results of these two components -- the direct effects of the solid waste management system and the indirect effects in the product manufacturing system -- into a total systems analysis. Here the data are presented in two forms: first, without allocation to geographic regions (the global perspective) and, second, with such allocation. The New York City solid waste management planning scenarios serve to illustrate how such total system estimates appear for a specified waste stream and management strategy.

The results of the global analysis appear in Table S-1. The energy impacts from recycling under the Manufacturing System entry are determined by multiplying the tons of each material diverted from the waste by the appropriate energy coefficient. Net energy recovery (indicated by a negative sign) and net use (indicated by a positive sign) are then added to the MSW and Special Waste Management Total and the waste wood combustion contribution to determine the total energy balance in each solid waste management scenario.

TABLE S-1. Solid Waste, Wood Waste Combustion, and Manufacturing System Energy Summary for Scenarios A,B,C, and D (TBtu/year) [1].

Energy Component	Scenario A	Scenario B	Scenario C	Scenario D
MSW Management: Residential, Institutional, and Commercial Waste [2]				
Collection	0.49	0.53	0.53	0.47
Processing	4.14	4.20	2.27	5.36
Transport	0.06	0.05	0.07	0.07
Disposal	0.02	0.01	0.02	0.01
Energy Generation[3]	-27.62	-25.41	-3.65	-38.16
SUBTOTAL	-22.91	-20.62	-0.76	-32.25
Special Waste Management: Sludge, Medical Waste, C&D, Harbor Drift, and Harbor Dredge [2]				
Collection	0.59	0.59	0.59	0.59
Processing	2.44	2.44	2.44	2.44
Transport	0.01	0.01	0.01	0.01
Disposal	0.01	0.01	0.01	0.01
Energy Generation [3]	-0.99	-0.99	-0.99	-0.99
SUBTOTAL	2.07	2.07	2.07	2.07
MSW and Special Waste Management Total	-20.84	-18.55	1.31	-30.18
Manufacturing System:				
Energy Impacts from Recycling [4]	-22.14	-22.34	-21.92	-8.81
Wood Waste Combustion[5]	-5.14	-5.14	-5.14	-5.14
TOTAL[6]	-48.13	-46.03	-25.76	-44.14

Notes:

[1] A positive value indicates energy is used by the activity. A negative value indicates that energy is produced or saved by the activity.

[2] Taken from Tables 2.12 and 2.13.

[3] Includes energy recovery from landfill gas and incineration.

[4] Taken from Appendix V-A (recyclables diverted from waste stream multiplied by coefficients from Table 5.1).

[5] Taken from Tables 4.1 and 4.2.

[6] The energy associated with used motor oil and tires is not included in this table. An estimated 10.3 million gallons of used motor oil [*], and 3.5 million tires [**] are produced each year in NYC. The energy saved if the waste oil was recycled is approximately .5 TBtu/year. If the oil was used as blended fuel, about 1.1 MMBtu of useable heat would be produced assuming a boiler efficiency of 80%. The energy produced by using the tires as kiln fuel is about 1.2 TBtu/year, assuming a kiln efficiency of 80%. Collection, transportation and processing energy requirements would have to be deducted from these totals to include these contributions in this table.

* Varandani, M., NYCDEP, Nov. 1993.

**Moore, G., NYCDOS, Nov. 1993.

Table S-2. Recyclables Diverted from the Waste Stream for Scenarios A,B,C, and D [1].

<u>Recyclable</u>	<u>Scenario A (tons/yr)</u>	<u>Scenario B (tons/yr)</u>	<u>Scenario C (tons/yr)</u>	<u>Scenario D (tons/yr)</u>
Paper/Paperboard:				
Corrugated Boxes/Kraft Paper	693,295	693,295	741,576	517,460
Newspapers	351,358	369,888	334,440	140,038
Office/Computer Paper	313,193	316,267	297,886	233,415
Mixed Paper	396,873	401,727	372,880	204,338
Plastics:				
HDPE Containers: clear and colored	78,251	79,649	82,410	31,191
LDPE Films and Bags	32,539	32,539	31,265	1,717
PET Containers: clear and green	32,750	33,199	34,124	12,923
Glass:				
Glass Containers: clear, green, and brown	72,276	74,550	77,996	38,276
Metal:				
Aluminum: cans, foil, misc.	46,245	45,548	45,341	9,712
Steel/Tin Food Containers, Ferrous Scrap	178,559	186,190	203,505	157,753
Miscellaneous:				
Brick/Concrete	555,163	555,163	555,163	555,163
Wood waste [2]	406,521	406,521	406,521	406,521
Total	<u>3,157,023</u>	<u>3,194,536</u>	<u>3,183,107</u>	<u>2,308,507</u>

[1] Recyclables from the MSW stream (i.e., residential, institutional, and commercial streams) except brick/concrete and non-bulk ceramics or batteries.

[2] Wood wastes are assumed to be combusted in special wood waste boilers after separation from the C&D waste stream.

TABLE S-3. SUMMARY OF MANUFACTURING SYSTEMS AND WOOD WASTE COMBUSTION ENERGY DATA
(MMBtu per ton intermediate or final product).

FINAL/INTERMEDIATE PRODUCT[6]	VIRGIN PRODUCTION	RECYCLED PRODUCTION	VIRGIN - RECYCLED	TONS WASTE/ [7] TON PRODUCT	ENERGY COEFFICIENT
Linerboard					
Total Energy	25.19	22.54	2.65	1.15	2.30
Production Process Energy	24.28	20.74			
Production Transportation Energy	0.91	1.44			
Recyclables Acquisition Energy [1]		0.36			
Newsprint					
Total Energy	28.30	17.64	10.66	1.17	9.11
Production Process Energy	27.81	15.55			
Production Transportation Energy	0.49	1.73			
Recyclables Acquisition Energy [1]		0.36			
Printing/Writing Paper					
Total Energy	27.64	17.27	10.37	1.14	9.10
Production Process Energy	26.62	16.19			
Production Transportation Energy	1.02	0.72			
Recyclables Acquisition Energy [1]		0.36			
Coated Folding Boxboard					
Total Energy	25.91	23.11	2.80	1.03	2.72
Production Process Energy	25.00	22.10			
Production Transportation Energy	0.91	0.65			
Recyclables Acquisition Energy [1]		0.36			
HDPE Pellets					
Total Energy	51.79	11.49	40.30	1.00	40.30
Production Process Energy	45.05	10.50			
Production Transportation Energy	6.74	0.63			
Recyclables Acquisition Energy [1]		0.36			
LDPE Pellets					
Total Energy	65.66	17.36	48.30	1.00	48.30
Production Process Energy	58.73	15.75			
Production Transportation Energy	6.93	1.25			
Recyclables Acquisition Energy [1]		0.36			
PET Pellets					
Total Energy	44.55	12.11	32.44	1.00	32.44
Production Process Energy	37.36	10.50			
Production Transportation Energy	7.19	1.25			
Recyclables Acquisition Energy [1]		0.36			
Molten Glass					
Total Energy	7.03	5.49	1.54	1.00	1.54
Production Process Energy	6.72	4.50			
Production Transportation Energy	0.31	0.63			
Recyclables Acquisition Energy [1]		0.36			

S-3 (CONTINUED). SUMMARY OF MANUFACTURING SYSTEMS AND WOOD WASTE COMBUSTION ENERGY DATA
(MMBtu per ton intermediate or final product).

FINAL/INTERMEDIATE PRODUCT	VIRGIN PRODUCTION	RECYCLED PRODUCTION	(VIRGIN - RECYCLED)	TONS WASTE/ TON PRODUCT	ENERGY COEFFICIENT
Molten Aluminum					
Total Energy	152.05	9.37	142.68	1.11	128.42
Production Process Energy	147.59	8.32			
Production Transportation Energy	4.46	0.69			
Recyclables Acquisition Energy [1]		0.36			
Molten Steel					
Total Energy	24.23	5.40	18.83	0.99 [2]	18.96 [8]
Production Process Energy[9]	23.47	4.42			
Production Transportation Energy	0.76	0.62			
Recyclables Acquisition Energy [1]		0.36			
Aggregate Road Base					
Total Energy	0.05	0.26	-0.21	1.00	-0.21
Production Process Energy					
Production Transportation Energy					
Recyclables Acquisition Energy [3]		0.26			
Lubricating Oil Base Stock (per bbl)					
Total Energy	2.58	0.68	1.90	1.00	1.90
Production Process Energy	2.36	0.42			
Production Transportation Energy	0.22	0.26			
Recyclables Acquisition Energy		n/a			

WOOD WASTE COMBUSTION

Wood Waste [4]					
Total Energy Value	NA	-12.64	NA	NA	-12.64
Energy Value[5]	NA	-12.90	NA		
Recyclables Acquisition Energy [3]	NA	0.26	NA		

Notes:

[1] Based on average energy value of 362,000 Btu/ton of recyclables from Scenarios A, B, and C of the New York City Solid Waste Management Planning Project. Includes collection and processing of recyclables, and transport of recycling residues.

[2] Secondary steel manufacturing requires some scrap iron to be added to the process mix, therefore the amount of scrap steel required is less than 2000 pounds/ton.

[3] Based on average energy value of 261,000 Btu/ton of construction and demolition waste (C&D) from Scenarios A, B, and C of the New York City Solid Waste Management Planning Project. Includes collection and processing of C&D, and transport of residues.

[4] Wood waste has no virgin production counterpart. Therefore, the energy coefficient for wood fuel combustion is the sum of the energy generated from its combustion plus the energy consumed in acquisition of the wood from the waste stream.

[5] Based on average energy value of 8600BTU per pound of oven-dried wood. Neal, Homer A. and Schubel, J.R., "Solid Waste Management and the Environment: The Mounting Garbage Crisis," Prentice-Hall, Inc., 1987. p.17.

[6] For each material, recycled and virgin product quality are assumed to be equal.

[7] Ratio reflects percentage of material lost during recycling manufacturing process as sludge or residue.

[8] This coefficient would be 16.45 if the industry average use of 13.5% prompt scrap in making "virgin" steel were used in addition to the 10% post consumer scrap use that is assumed in this analysis (see p.3-24).

[9] Assumes a mix of 10% post-consumer content, which uses recycled steel energy inputs, plus 13.5% prompt scrap, which uses virgin steel energy inputs.

Prior to including the effects of recycling, all but Scenario C (the combustion-free scenario) show a positive system balance; that is, recovery and savings exceeds use. Scenario D, the combustion-intensive scenario, shows the strongest positive balance with over 30 TBtu (trillion or 10^{12} Btu). Once the recycling energy impacts are added, all four show a positive balance, reflecting the benefits of using waste as material and energy resources.

On the energy use side, the largest impacts are attributable to processing, including materials separation and composting. Collection and transportation energy are relatively minor contributors. On the recovery and savings side, the largest contributors are waste combustion with energy recovery, energy saved by manufacturing processes using recycled versus virgin materials, and energy generated by wood waste combustion. Scenarios A, B, and D, all featuring a combination of recycling and combustion with energy recovery, show a substantial positive system energy balance of approximately twice that of the combustion-free Scenario C.

Using two of the four scenarios as case studies, we developed and applied a methodology for assigning these impacts to four geographic regions: New York City, New York State, U.S. excluding New York, and Outside the U.S. This requires an assessment of where recycled production would take place, and in which regions virgin production would be displaced.

Tables S-4 and S-5 show the results of this spatial allocation for scenarios B and D, respectively. In Scenario B, the U.S. outside New York State is the greatest beneficiary of the systems-wide energy savings, reflecting the reduced energy use in a diversity of U.S. industries that utilize recovered waste materials as industrial feedstock instead of virgin materials. The City and State are, respectively, a lesser though still significant beneficiary and a net user (i.e., uses exceed recovery plus savings). In contrast, Scenario D shows the City and Outside the U.S. approximately equal beneficiaries of a combustion-intensive management system, while the State again shows uses exceeding energy recovered plus saved energy, at a level about equal to Scenario B. This net use is linked to the location of new manufacturing industries (as opposed to restructured virgin materials facilities) established in the state to capitalize on large volumes of recovered wastes from the City's recycling programs. Because in the spatial analysis process energy is not allocated to co-products and transport energy is not allocated by region, the bottom-line figures in S-4 and 5 slightly different than those reported in S-1.

TABLE S-4. RESULTS OF SPATIAL ANALYSIS FOR REGIONS 1-4, FOR SCENARIO B.

Region	SW System/ Recy./Virgin Manufacturing	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption				Total (MMBtu/yr)
				Oil (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other[1] (MMBtu/yr)	
1 = NYC	SW System [2]						-1.85E+07	
	Recycled [3]	9.46E+06	7.42E+05					
	Virgin [4]							
	Net Energy [5]	9.46E+06	7.42E+05					
	Net MMBtu[6]	9.93E+04	1.04E+03				-1.85E+07	-1.84E+07
2 = NYS (excluding NYC)	Recycled	5.39E+08	6.04E+09	8.91E+02	2.89E+08	3.17E+02	1.14E+02	
	Virgin	-2.57E+07	-6.54E+08	-6.58E+05	-3.44E+08	0.00E+00	-1.86E+04	
	Net Energy	5.13E+08	5.38E+09	-6.57E+05	-5.51E+07	3.17E+02	-1.85E+04	
	Net MMBtu	5.39E+06	7.53E+06	-9.84E+04	-5.68E+04	7.93E+03	-1.85E+04	1.28E+07
3 = U.S. (excluding NYS)	Recycled	2.82E+08	2.10E+09	8.91E+02	2.77E+08	3.17E+02	1.14E+02	
	Virgin	-1.23E+09	-1.98E+10	-2.00E+07	-3.82E+09	-1.11E+05	-5.16E+06	
	Net Energy	-9.47E+08	-1.77E+10	-2.00E+07	-3.54E+09	-1.11E+05	-5.16E+06	
	Net MMBtu	-9.94E+06	-2.48E+07	-3.00E+06	-3.65E+06	-2.77E+06	-5.16E+06	-4.93E+07
4 = Outside of U.S.)	Recycled	4.47E+08	5.98E+09					
	Virgin	-2.84E+08	-8.43E+08	-1.51E+06	-2.42E+08	-1.13E+03	-1.22E+03	
	Net Energy	1.63E+08	5.14E+09	-1.51E+06	-2.42E+08	-1.13E+03	-1.22E+03	
	Net MMBtu	1.71E+06	7.19E+06	-2.26E+05	-2.50E+05	-2.82E+04	-1.22E+03	8.40E+06

Net Energy for Regions 1 through 4:

-4.65E+07

-46.5 TBtu/yr.

Notes:

[1] Other Process Fuels refers to remaining fuels other than natural gas, coal, or oil, such as gasoline, propane, etc.

[2] From Table 5.2. Includes MSW and Special Waste management, energy use, and recovery. Wood waste was not included in the spatial analysis as it is not recycled in the same manner as traditional recyclables. It is combusted to produce energy not a wood product.

[3] Energy used in the region to manufacture new products from recyclables.

[4] Energy use displaced (i.e., not used) in region by manufacture of new products from recyclables.

[5] The sum of recycling energy use and virgin energy displaced for region, in units of kWh/yr electricity, pounds/yr steam, etc.

[6] The sum of recycling energy use and virgin energy displaced for region, in units of MMBtu/yr.

TABLE S-5. RESULTS OF SPATIAL ANALYSIS FOR REGIONS 1-4, FOR SCENARIO D.

Region	SW System/ Recy./Virgin Manufacturing	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption				Total (MMBtu/yr)
				Oil (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other[1] (MMBtu/yr)	
1 = NYC	SW System [2]						-3.02E+07	
	Recycled [3]	9.46E+06	7.42E+05					
	Virgin [4]							
	Net Energy[5]	9.46E+06	7.42E+05					
	Net MMBtu[6]	9.93E+04	1.04E+03				-3.02E+07	-3.01E+07
2 = NYS (excluding NYC)	Recycled	5.31E+08	6.04E+09	7.55E+02	1.54E+08	2.69E+02	9.65E+01	
	Virgin	-2.38E+07	-6.54E+08	-6.57E+05	-1.76E+08	0.00E+00	-9.54E+03	
	Net Energy	5.07E+08	5.38E+09	-6.56E+05	-2.25E+07	2.69E+02	-9.45E+03	
	Net MMBtu	5.32E+06	7.53E+06	-9.83E+04	-2.32E+04	6.72E+03	-9.45E+03	1.27E+07
3 = U.S. (excluding NYS)	Recycled	9.25E+07	1.05E+09	7.55E+02	7.00E+07	2.69E+02	9.65E+01	
	Virgin	-5.15E+08	-1.29E+10	-1.23E+07	-1.28E+09	-9.26E+04	-2.00E+06	
	Net Energy	-4.23E+08	-1.18E+10	-1.23E+07	-1.21E+09	-9.23E+04	-2.00E+06	
	Net MMBtu	-4.44E+06	-1.65E+07	-1.85E+06	-1.24E+06	-2.31E+06	-2.00E+06	-2.84E+07
4 = Outside of U.S.)	Recycled	1.10E+08	1.70E+09					
	Virgin	-1.06E+08	-3.17E+08	-4.73E+05	-5.16E+07	-2.40E+02	-2.65E+02	
	Net Energy	3.93E+06	1.38E+09	-4.73E+05	-5.16E+07	-2.40E+02	-2.65E+02	
	Net MMBtu	4.13E+04	1.93E+06	-7.08E+04	-5.32E+04	-6.00E+03	-2.65E+02	1.84E+06

Net Energy for Regions 1 through 4:

-4.39E+07

Notes:

[1] Other Process Fuels refers to remaining fuels other than natural gas, coal, or oil, such as gasoline, propane, etc.

[2] From Table 5.2. Includes MSW and Special Waste management, energy use, and recovery. Wood waste was not included in the spatial analysis as it is not recycled in the same manner as traditional recyclables. It is combusted to produce energy not a wood product.

[3] Energy used in the region to manufacture new products from recyclables.

[4] Energy use displaced (i.e., not used) in region by manufacture of new products from recyclables.

[5] The sum of recycling energy use and virgin energy displaced for region, in units of kWh/yr electricity, pounds/yr steam, etc.

[6] The sum of recycling energy use and virgin energy displaced for region, in units of MMBtu/yr.

Keeping in mind the multitude of assumptions underlying solid waste management, secondary materials manufacturing, and spatial analyses, our study suggests the following general conclusions:

- In sum, all four scenarios show a positive energy balance indicating the energy advantage of integrated systems versus reliance on one or a few technology options. That is, energy produced or saved exceeds the energy used to operate the solid waste system. The largest energy use impacts are attributable to processing, including materials separation and composting. Collection and transportation energy are relatively minor contributors. The largest two contributors to net energy savings are waste combustion and energy saved by processing recycled versus virgin materials.
- In comparing energy flows in collection, processing, transport, and disposal, it is the processing step that dominates energy use regardless of the mix of recycling, composting, combustion, and landfilling that comprise a given system. In the four scenarios we examined, processing represents between 88-95% of energy use in the direct waste management system.
- Within the confines of the direct solid waste management system, exclusive of indirect (secondary manufacturing) effects, intensive use of combustion yields a relatively high net energy balance. This is the case even though combustion systems use substantial energy in operation. In comparison to relatively modest combustion scenarios in which combustion handles 39 to 45% of the waste stream, a 63% combustion scenario adds approximately 50% to the system energy balance, after accounting for all uses and generation in the waste management system, including special wastes.
- With one minor exception, recycle manufacturing systems demonstrate greater energy efficiency than virgin systems. The range of these differences is enormous. At the high end is aluminum for which the difference in virgin versus secondary production (the energy coefficient) is 128.42 MMBtu per ton of intermediate product. In the intermediate range (30-50 MMBtu), coefficients are products such as HDPE pellets, LDPE pellets, PET pellets. And at the lowest range (under 5 MMBtu) are linerboard, boxboard, molten glass, and aggregate road base (the only negative coefficient). In all cases, it is the production process energy functions (versus collection, transportation, and preprocessing) that dominate the manufacturing systems energy requirements.
- With the exception of the combustion-intensive scenario and leaving aside wood waste combustion (which is handled separately in the scenario development), the indirect energy effects of diverting waste materials to secondary materials exceeds the energy used for these materials in direct

management systems. This difference ranges from a factor of 1.2 to 17.7; that is, secondary manufacturing accounts for slightly more than half and up to 94% of the positive systems-wide energy balance. Thus, in management systems that rely moderately to heavily on recycling and composting, the bulk of the net energy benefits are attributable to the energy efficiency inherent in secondary materials manufacturing made possible by the recovery of materials from residential, institutional, and commercial waste streams. In contrast, in the combustion-intensive scenario, energy recovery dominates the energy balance. In this case, the direct system effects exceed those of the secondary manufacturing effects by a factor of 3.4; that is, the direct management system (and largely waste-to-energy) accounts for over two-thirds of positive systems balance.

- The spatial impacts of energy benefits are highly diffuse. Using the allocation methodology in this study, heavy reliance on combustion creates substantial localized energy benefits for New York City, exceeding energy savings in the U.S. outside New York State. More modest levels of combustion change this profile. In this case, energy benefits are concentrated in the U.S. outside New York State, a result of the substantial and diffuse savings of secondary materials manufacturers that use New York City's recycled wastes as industrial feedstock.
- New York State outside New York City will feel the effects of energy use by new recycling industries, and this will offset the savings of displacing virgin production in the state. While the impacts statewide of diverting New York City's waste are small in absolute terms -- probably about 1% of statewide energy use -- localized and regional impacts may well be of some consequence. This would occur if, for example, major, new, electricity-intensive recycling industries co-locate in a single utility-service territory. Planning for such developments is a logical component of any statewide energy planning program.
- Scenarios A, B, and D, all featuring a combination of recycling and combustion with energy recovery, show a substantial positive balance of approximately twice that of the combustion-free Scenario C. Thus, notwithstanding the spatial distribution of energy benefits, a mix of waste management approaches is essential for maximizing system-wide energy benefits.
- From a planning perspective, energy requirements per ton of product for virgin versus recycle materials manufacturing is not only a matter of quantity, but also source and type -- purchased versus on-site, renewable versus fossil. Recycle paper products such as linerboard, printing/writing paper, and boxboard, require more purchased energy on a per ton basis than their virgin

counterparts. Moreover, the energy recovered on site from wood residues, which amounts to about 11 to 70% of total energy needs for these three paper products, is a renewable source unlike fossil-generated off-site electricity purchases. Other materials such as aluminum, plastics, and steel also use recovered energy from on-site sources, though only in modest quantities and not from renewable sources. In any case, effective energy planning to meet the needs of future secondary materials industries requires consideration of source and type, in addition to total quantity.

The methodology and scenarios in this study provide a foundation for further exploration of the solid waste - energy interactions. The analytical framework is receptive to alternative assumptions, as well as new data on energy flows in both the solid waste management system and/or secondary materials manufacturing sector. Future applications of our approach promise to provide valuable insights into predicting how much, what type, and where energy impacts will occur as solid waste management systems continue to move from single facility to more integrated, and complex, configurations.

Finally, our experience in developing and applying our methodology points to the following five items for future research directions:

- **Market demand for recyclables.** Our analysis assumes all recyclable materials will find a market rather than be diverted to processing and disposal facilities. Given uncertainties in the development of secondary materials markets, sensitivity analysis under conditions of less than 100% marketability of recyclables merits further consideration.
- **Future regulatory requirements.** Air and water pollution standards; compost, sludge and ash classification; and revisions to landfill standards may affect the options available to waste managers. Incorporating such changes into future scenarios by altering diversion rates to various facility types would enable an assessment of the consequences of future regulatory requirements.
- **Upgrading data sources.** While we believe all manufacturing data sources are the best available within the public domain, additional data development would strengthen future analyses. This is especially true for plastics recycling, where data were difficult to obtain and subject to early obsolescence because of rapid technological changes in the industry.
- **Expanding the covered wastes.** Future analyses would benefit from including additional components, especially tires and waste oil. Also it would be beneficial to examine polypropylene, PVC, and polystyrene plastics. Though small in volume terms, these represent potentially substantial energy implications on a systems-wide basis.

- **Indirect impacts within the solid waste management system.** Excluded from the analysis are energy implications of operating additional wastewater treatment facilities tied to higher rates of recycling in households and institutions. Assessing these and other such indirect effects of recycling would add a valuable dimension to future systems studies.

Section 1

INTRODUCTION

Traditional, single-facility municipal solid waste (MSW) management practices are gradually giving way to more complex systems emphasizing integrated, multi-facility approaches designed to divert waste from landfills to re-use and recycling, composting, and combustion. In New York State, as in most of the U.S., this transition has been spurred by the closing and cost of existing landfills, difficulty in siting new activities, and an awareness of the resource and environmental benefits of reduction, recycling, and re-use.

One result of this transition is a change in the way energy is used and recovered at each stage of the waste management process: collection of waste from generators, transport of waste between management facilities, processing of recyclables and compostables, burning or burying waste, and energy recovery from waste combustors and landfill gas. Each change in the configuration of a management system triggers a change in energy use and recovery.

Energy use is affected by changes in the number, type, and size of collection vehicles; their fuel efficiency; and the configuration of the collection routes as new recycling and compost collection systems are put in place. Distances to processing and disposal facilities change as new facilities are added, as local facilities replace regional facilities, and vice versa. And energy use and recovery at the facilities varies greatly for each system configuration according to the number and types of facilities used for processing, combustion, and disposal, facility design; size; and operating practices. A new community curbside recycling program, for example, may require a second collection vehicle to serve neighborhoods whose waste is destined for a materials recycling facility. Both the new collection vehicle and the facility itself require additional energy resources, but at the same time, they may reduce transport to a remote landfill site. In like fashion, the recovery of steam and electricity from combustion, and methane from landfills adds to the energy recovery side of the ledger, helping to shape the ultimate system-wide use and recovery accounts.

Beyond these first-order effects within the solid waste management system, the use of recovered materials (i.e., recyclables) as feedstocks in manufacturing activities triggers second-order effects by both increasing product manufacturing from recyclable material and displacing the virgin material-based production. These effects carry their own set of energy implications. When paper, plastic, aluminum, and ferrous products made from recovered materials displace those made from virgin

raw materials, a chain of impacts in the virgin manufacturing system is created. These impacts begin with virgin raw material extraction, and continue on through raw material transport, and intermediate and final production activities.

Though secondary materials manufacturing at first glance appears to be more energy efficient per unit of product output than virgin manufacturing, a closer look reveals a more complex situation requiring an integrated analysis before drawing such conclusions. Questions of *how much*, as well as *where*, energy is used in virgin and secondary manufacturing systems are two dimensions of interest to energy planners and waste managers.

An initial glimpse of this problem was developed in a February 1990 report prepared by Tellus Institute for the Coalition of Northeastern Governors/Northeast Regional Biomass Program (CONEG/NRBP) entitled, Energy Implications of Alternative Solid Waste Management Systems. In this project, we developed and applied a methodology for estimating energy balances for alternative waste management systems in 11 Northeastern states. Several limitations applied: modeling of residential wastes, and commingled and drop-off recycle systems only; composting technologies that included only drop-off and paper bag collections; an incomplete inventory of vehicle types, and facility technologies and scales; identification of only seven points of energy use and three points of energy recovery in the solid waste management system; and no analysis of the incidence of use and recovery impacts. In addition, and most importantly, estimates of energy savings through secondary materials manufacturing were based on rough estimates using often outdated estimates of net savings.

Notwithstanding these limitations, the results were provocative. In the New York State case, using the state's solid waste master plan, over 90% of the (positive) energy balance (savings minus use) was tied to energy saved from the displacement of virgin manufacturing by manufacturing using materials recovered from the solid waste stream. This finding suggested that a systems analysis -- one that includes impacts *both* within the solid waste management system and the product manufacturing system -- shows a significant energy benefit associated with high rates of recycling.

While the CONEG/NRBP report represented a first step in assessing solid waste-energy interactions, a more comprehensive analysis promised to yield a more refined picture of how different waste diversion configurations contribute to changing system-wide energy balances. Such an opportunity emerged in 1991 in connection with New York City's ongoing solid waste master planning process. As the City proceeded to develop an extensive technology, economic, and environmental database for assessing its 20-year management options, it also agreed to include energy as one component of its Generic Environmental Impact Statement (GEIS) for alternative waste planning scenarios. This, in turn, represented a convenient vehicle and rich database

for taking the earlier CONEG study to a higher level of refinement by enlarging the number of collection programs and facility types well beyond those used in the CONEG analysis. At the same time, the New York City study was a timely starting point to improve the rough estimates of secondary materials manufacturing energy data, which were the key determinant of the statewide energy balances estimated earlier.

In sum, our objective in this study is to develop and apply an integrated methodology for assessing the energy implications of alternative solid waste management systems. Two principal audiences are, first, the New York State and other state energy offices charged with long-range planning and, second, county and municipal solid waste managers interested in estimating the energy requirements and costs of local solid waste master plans.

Our report is divided into six sections. Following this introduction, **Section 2** presents a conceptual framework for estimating energy impacts of the solid waste management system, the first of two major elements in estimating total systems impacts. Here we revisit the earlier CONEG work and identify all waste collection, transport, processing, and disposal activities where energy use and recovery occurs. Using New York City as a case study, we apply this framework to four scenarios containing various mixes of collection systems and facilities to compute an energy balance for each scenario.

Section 3 presents a complementary framework for virgin and secondary materials manufacturing. This framework maps the production cycle of selected materials in the NYC waste stream along two pathways: products made from virgin materials and the same product largely, or exclusively, made from recycled materials. All energy uses in the production cycle are tracked up to the point where virgin and recycle manufacturing processes converge. We make certain assumptions regarding how far away from the principal production pathways -- extraction, transport, intermediate processing, final processing -- energy impacts are tracked. From this analysis emerges an energy coefficient representing the difference, expressed in Btus per ton of waste handled, in virgin versus recycle manufacturing energy requirements.

Section 4 presents a brief analysis of wood wastes, a waste stream distinct from others in that its principal recovered use is boiler fuel rather than secondary materials manufacturing.

Section 5 combines the results of two components -- the direct effects of the solid waste management system and the indirect effects within the product manufacturing system -- into a total system estimate of energy impacts for four New York City solid waste management scenarios. Using two of the four scenarios as case studies, we develop and apply a methodology for assigning these impacts to four geographic regions: New York City, New York State, U.S., and elsewhere. We refer to this as

the spatial analysis of energy impacts from the New York City solid waste management plan.

Finally, **Section 6** highlights our major findings and conclusions, strengths and limitations of the analysis, and directions for future data development and applications.

In conjunction with this study, Tellus developed a spreadsheet model to facilitate the task of estimating statewide energy impacts of solid waste management systems.¹ The Solid Waste Energy Evaluation Tool (SWEET) was developed to bridge the gap between state energy planning and solid waste planning. With user inputs and a set of default data² the model estimates statewide energy impacts for any specified solid waste management system configuration. Total annual energy usage is reported along with relevant energy generation data to yield net energy requirements associated with a given solid waste management system. A total of five waste management streams can be modeled: residential, commercial/institutional, construction and demolition (C&D), sludge, and medical waste systems.

SWEET has been transferred to the Energy Authority, and is available to other energy and waste planners to facilitate future assessments of the energy implications of integrated solid waste management systems.

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¹ SWEET was designed for statewide energy impact analyses and is not suitable for local-level solid waste planning, which typically is performed at a higher level of disaggregation.

² The default data is based on the New York City Department of Sanitation GEIS and the data developed in this study.

Section 2¹

ENERGY IMPACTS OF THE SOLID WASTE MANAGEMENT SYSTEM

This section examines energy use and recovery in managing solid waste, the first of two major elements in an integrated systems analysis. The second element, secondary manufacturing energy impacts, is the subject of Section 3. We begin by presenting a general framework for the analysis of energy impacts of the solid waste management system (Section: Defining the System). We then move on to a case study of energy impacts of four solid waste system planning scenarios to demonstrate how energy use and recovery varies for each distinctive solid waste management system scenarios (Section: Case Study: New York City - Year 2000).

The general framework for the energy analysis was developed in conjunction with New York City's recently completed solid waste management planning process (referred to below as the "GEIS planning process"). An initial energy analysis based on the New York City scenarios was completed in September 1992. The initial draft of this report was sent to a variety of experts in the field selected by the Energy Authority, which provided comments on data and methods. These are addressed in this Final Report.

In addition to outside experts, the New York City Department of Sanitation was contacted to provide updated information pertaining to solid waste collection systems, which were initially modeled in the four solid waste management scenarios.² In some cases, more accurate and/or up-to-date information replaces data developed in the initial GEIS planning process. Appendix II-A describes all assumptions pertaining to the development of collection system data.

Finally, in this updated analysis, data and assumptions pertaining to waste combustion have been revised to more accurately estimate the energy generated through municipal waste combustion.

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¹ Appendix II corresponds to this section.

² Letters were sent and follow-up calls were made to the following DOS Bureau of Cleaning and Collection personnel in June 1993: Joseph Timpone, Director; Mitch Zaretski, Executive Assistant to the Director; Renetta Smith, Assistant to Commissioner Laowitz. Additionally, all collection system data utilized in this analysis were provided for review to Alex Prutkovsky, Operations, Planning, Evaluations, and Control unit in July 1993.

DEFINING THE SYSTEM

For purposes of energy analysis, the system is defined by solid waste system boundaries and energy impact boundaries. We discuss each of these in turn, and synthesize the two into a general analytical approach for calculating energy impacts. Given the complexity of New York City's waste stream, collection programs, and facility options, the solid waste planning process is substantially more complicated than most other localities or states are likely to undertake. Of course, New York City's solid waste system is unique inasmuch as it services the largest city in the nation. Thus, while the framework we propose does represent the outer bounds of complexity any system might entail, it may be simplified for future applications in more typical communities.

Solid Waste Management System

The purpose of a solid waste management system is to collect, transport, process, and dispose of the materials in the waste stream. The system comprises a set of waste generation points, transport links, and transfer/processing and disposal facilities. Figure 2-1 illustrates the flow of waste from collection, to transfer, processing and final disposal. Thus, by system, we mean the waste streams, activities, and facilities included in the waste management system. The system begins with the collection of materials, continues with the processing of these materials, and ends with different materials destinations: a product such as compost or recyclables as material input; energy generation from waste combustion; or waste materials such as non-processed materials, ash, and processing residuals that are destined for disposal in a landfill.

In our analysis, we define the following:

- a. Waste Stream Boundaries
  - 1) Municipal solid waste (MSW):
    - a) Residential
    - b) Institutional
    - c) Commercial (including industrial)
  - 2) Special waste (non-MSW):
    - a) Construction and demolition debris
    - b) Sewage sludge
    - c) Medical waste ("red bag" waste)
    - d) Harbor debris (floatables and pier waste)
    - e) Dredge spoils (harbor dredging)

Figure 2-1. Solid Waste Management System Overview.

b. Activity Boundaries

- 1) The collection of waste from residences, institutions, and commercial enterprises, either by public or private hauler, exclusive of drop-off of household waste by residents at a landfill or transfer station
- 2) The transportation of waste from a collection point to a facility
- 3) The transportation of waste and residues from one waste handling facility to another
- 4) The operation of waste management facilities

c. Facility Boundaries (types)

- 1) Waste transfer facilities
- 2) Processing facilities (e.g., materials recovery facilities, municipal waste combustors, and mixed waste processing facilities³)
- 3) Composting facilities
- 4) Landfills.

Impact Analysis

Energy use and recovery occur at multiple points throughout a solid waste management system. Energy is used to operate trucks that collect and transport garbage from homes or businesses to transfer stations, processing facilities, municipal waste combustors and landfills. Energy also is used to operate processing facilities, municipal waste combustors, and landfills. In addition, energy can be recovered from the solid waste management system either through the combustion of waste or the recovery of methane gas from landfills. In general, it is useful to distinguish between two types of impacts:

1) Direct Energy Impacts

- Energy used to operate vehicles for collection and transport of waste to a management facility.
- Energy used to transport waste from one management facility to another.

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³ Mixed waste processors, as modelled in the New York City scenarios, are designed to capture and process recyclables from the commercial waste stream. They are used as a final separation stage prior to the combustion or burying of waste, and are designed to be at the front end of transfer facilities. Recyclables are processed and sent to market. While these facilities are associated with a transfer station, they are modelled as distinct facilities in order to track material flows and energy use.

- Energy used to operate processing facilities, municipal waste combustors, and landfills.
- Energy used to process and handle residue from waste processing, that is **non-product** outputs from processing facilities at waste management facilities, and
- Energy recovered from municipal waste combustors and landfills.

2) Indirect Energy Impacts

Certain "indirect" impacts occur as a result of managing waste in a solid waste system. An example of such an indirect impact is the energy use required in pumping and heating water that may be used in the households to rinse recyclable glass, metal and plastic containers, and the energy needed to treat the wastewater and dispose of the sludge that results from this household precleaning of recyclables.

These types of indirect effects are numerous, vary greatly, and are difficult to quantify. As a case in point, it may not be necessary to rinse out containers before setting them out for collection, although some people prefer to in order to control odors if the materials must sit some time before being put out for curbside collection or being taken to a drop-off facility. In fact, many communities require prerinsing of recyclables to control vectors as well as odors if materials are to be collected at the curb, or hand separated at a processing facility. In addition, many recycled materials brokers prefer cleaner materials. In any event, it is difficult to estimate: the percentage of households that rinse out recyclables, and equally difficult to initially estimate the energy impact associated with this activity. Specifically, it is difficult to estimate a) the average quantity of water used in this activity, b) the temperature of the water (and therefore the energy necessary to heat it), c) the relative energy contribution to the wastewater treatment plant, and d) the relative energy contribution for wastewater treatment sludge disposal. Though indirect energy impacts may be significant when examined in the aggregate, a paucity of data prevented us from including these impacts in our analysis.

Analytical Approach

To develop an energy analysis of a solid waste management system, three steps are necessary.

Step 1:   **Describe the waste management system.** This includes:

- a)   The quantity, composition, and Btu value of the waste stream(s)
- b)   The number, types and sizes of waste management facilities employed
- c)   The quantity of waste handled by each facility
- d)   The number, types, and sizes of vehicles used for collection and transport of waste and processing residues from one facility to another
- e)   Either distance traveled by collection and transport vehicles or hours of vehicle operation.

Step 2:   **Develop energy use and recovery values for all relevant activities in the system,** including all types and sizes of facilities, collection, and transport vehicles.

Step 3:   **Apply energy use and recovery data to waste management system data from Step 1,** to calculate energy use and recovery for each activity. Using a set of algorithms, the system energy data may then be summarized to produce annual energy impacts for the total system, and subsystems (such as the recycling subsystem), and per ton energy values that reflect the energy intensity of the whole system or a subsystem. This per ton value can be used to compare the energy impact of different waste management system scenarios.

We operationalized this approach in conducting a case study of the energy impacts of the New York City Solid Waste Management Plan. This exercise provided a vehicle for iteratively testing and refining the methodology.

CASE STUDY: NEW YORK CITY - YEAR 2000

In this section, we present the methodology, data, and results of an analysis of the energy impacts of four solid waste planning scenarios developed by Tellus for the City of New York. We begin this section with an overview of the New York City Solid Waste Management Planning Process and **WastePlan**, the software planning tool used to create the two management scenarios we analyze.

Overview of the New York City Solid Waste Planning Processes

The New York City Department of Sanitation (DOS) has developed a 20-year plan for all solid waste generated within the City of New York. The waste included in this plan is divided into six separate waste streams defined by the type of waste found within each stream. This division into waste streams applies to waste generated or collected by public or private entity. The six streams are:

- Municipal solid waste (MSW), comprising residential, institutional, commercial, and industrial wastes
- Construction and demolition debris
- Sewage sludge
- Regulated medical waste, otherwise known as "red bag" waste
- Harbor debris, mostly wood waste from decaying piers in the waters surrounding New York City and other materials flushed through the city's storm drains
- Dredge spoils, created from the maintenance of the city's waterways.

Of the six streams, the MSW stream was the most significant. It accounts for the overwhelming majority of waste generated in New York City and contains the two types of waste -- residential and institutional -- for which the DOS has primary responsibility. Thus, the greatest effort in preparing a solid waste management plan was reserved for the municipal waste stream in general, and the residential and institutional waste streams in particular.

In collaboration with DOS, four scenarios for an integrated plan were modeled with **WastePlan**, a micro-computer tool developed by Tellus for use in integrated solid waste planning. **WastePlan** details the type and tonnage of materials collected, vehicle requirements, the type and tonnage of material transferred or processed at each facility, the number and sizes of the facility types required, and capital and operating costs for all solid waste management activities. In order to accommodate the unique planning requirements of New York City, Tellus greatly enhanced the **WastePlan** model, using a version so named **New York City WastePlan**. All future references to the **WastePlan** model used in this study refer to the **New York City WastePlan** version of the model.

The New York City Solid Waste Management Master Plan was developed as a Generic Environmental Impact Statement (GEIS) to facilitate its implementation. Every element of the plan with an environmental impact, in particular the collection, processing and disposal of waste, was analyzed for effects on air, water, socioeconomic status, and traffic. Before this analysis could be performed, however, the plan had to be fully developed in extreme detail. For example, necessary

information included the number of collection vehicles operating daily in each of the city's 59 sanitation districts. Following below is a detailed description of the planning process and methodology used in the development of that plan. We provide this as necessary background to understand the complexity of the system-wide energy analysis that follows.

Initial Planning--Development of Waste Generation Data

The underpinning of any solid waste management plan is developing accurate and reliable data about waste generation. Since New York City required the development of a 20-year plan, any analysis of waste generation had to be projected over this time horizon. The development of baseline waste generation data was performed through a combination of field study and research by SCS Engineers, Inc.⁴ Their study developed two key pieces of information about each of the waste generating sectors:

- Total waste generated by waste generating (or "activity") units
- Composition of the generated waste.

The activity unit is simply a convenient unit for which the generation of waste is best understood. For example, in the residential sector typical activity units are "households" and "individuals." In a commercial sector activity units may be "employees," or "thousand dollars of sales."

The data developed by SCS were further refined and then projected over the 20-year planning period by Tellus in a companion study that developed a statistical profile for all six waste generating sectors and then forecast the growth in these sectors, both in terms of number of waste generators and amount of waste generated per unit.⁵ All solid waste data tables reflect the amount of waste to be managed in the year 2000. The resulting analysis presented data not only about waste generation rates, projected growth in waste generating units and composition by waste generating sector,⁶ but also material densities and a chemical analysis of each waste type. In this way more than 45 waste types were defined in the residential sector and more than 25 in the commercial and institutional sectors.

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⁴SCS Engineers, Inc. "New York City Municipal Solid Waste Generation and Composition," 1991.

⁵ John Stutz and Gary Prince. Statistical Profile of New York City for Solid Waste Management Planning, Tellus Institute, 1991.

⁶ Composition in the residential sector was determined for three different levels of housing density; composition in the institutional and commercial sectors was ascribed to subsectors such as: "transportation," "airports," and "government" in the institutional sector and "manufacturing," "non-food retail," and "restaurants" in the commercial sector.

The result of this analysis is presented in the New York City Solid Waste Management Master Plan and Generic Environmental Impact Statement (hereafter NYC GEIS). This forms the foundation of all planning and analysis regarding the collection and processing of that waste.⁷ Much of the data regarding waste generation and composition are specific to New York City. Among all types of data, only waste density and chemical composition are applicable to the world at large. Future analysts should carefully review other data elements to be sure they are transferable to local conditions.

Next Steps--Creating Collection Scenarios

WastePlan was used to analyze the many collection programs investigated in conducting the New York City GEIS study. The results of a **WastePlan** analysis provides a wealth of information regarding the economics and operating parameters of the collection programs under consideration. But, conversely, the computer model's requirements for input variables are substantial. Each collection program analyzed in the New York City planning process required inputs for a minimum of 17 types of variables relating to the physical operation of the program.⁸ This number does not take into account variables relating to program economics.

The methodology employed to produce these inputs for the collection programs under consideration entailed the development of baseline collection program conditions for New York City in 1990. Information in this baseline analysis described the operating conditions and collection efficiencies of vehicles and collection crews as they operated on the streets of New York in 1990.⁹ Based on this information, operating parameters were developed for future, modeled collection programs in each of the boroughs and 59 sanitation districts in New York City for the four final scenarios (and intermediate scenarios leading to them). Because this methodology relied heavily on data from New York City, much of the collection data is city-specific. Only data about the physical characteristics of the vehicles used to collect waste are applicable in other instances.

The end result of this process was a document -- the Baseline Analysis -- that describes source separation diversion rates, the speed at which collection vehicles travelled in their districts, the number of stops per hour made by vehicles in areas of different housing densities, and a host of other data necessary to the analysis of

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⁷ See New York City Department of Sanitation, GEIS Appendix 7-A.2 Waste Stream Characteristics, 1992.

⁸ A discussion of these variables and their derivation is included in Appendix II-A.

⁹ See New York City Department of Sanitation, GEIS Appendix 4-0: Baseline Analysis of Collection/Processing/Disposal Systems, 1992.

collection programs. For the residential sector this data was organized by density of the residential housing stock, and was customized to each sanitation district or zone by weighting it by the proportion of each type of housing stock density in each district.

The development of data about collection programs came from two principal sources: literature reviews by three independent consulting firms, and DOS. New York City, in particular, possessed encyclopedic information regarding most aspects of the collection programs they operated in the residential and institutional sectors. This data ranged from the type and number of collection vehicles used for recycling, leaf and yardwaste and refuse programs in each of the city's 59 sanitation districts and 12 sanitation zones, to the number of minutes required for a vehicle to drive from the center of its district to its principal and secondary drop-off points. Where key data were missing, such as the number of stops per hour made by a collection vehicle in a high density neighborhood, **WastePlan** solved for the missing variable.

In descending order from the institutional to the commercial and then to the special waste streams, the strength and availability of data faded in terms of its breadth and depth. Though the DOS had solid data about the institutional waste stream, the wide and random distribution of generating units in this sector required modeling compromises in the development of institutional collection programs. An "Institutional Baseline Analysis" outlines these compromises. The main one is the assignment of a uniform collection vehicle for all institutional programs.

Data from the commercial sector did not exist in any form from New York City, so much was inferred from the institutional programs, which shared many operational characteristics with the commercial programs. Some data were, however, culled from the commercial waste haulers themselves, who agreed to participate in several information-gathering sessions with representatives from the DOS and its consultants.

Data regarding the special waste streams were quite weak, though a number of studies evaluating the generation of harbor debris and construction and demolition debris were conducted and utilized in the NYC GEIS process. An in-depth study of regulated medical waste was conducted by the New York City Health and Hospitals Corporation, and that study was similarly incorporated into the NYC GEIS process.

Final Stages--Processing and Disposing of Collected Wastes

Once collected, waste must be processed and disposed of as appropriate. Except for the marine transfer stations and the city's three operating municipal waste combustors, data from the facilities employed to process waste in New York City in 1990 were not applicable to the GEIS study. This inability to apply data from existing to projected conditions arose from two sources:

- The existing facilities were few in number and much too small for consideration in an expanded, city-wide plan
- The plan called for types of processing facilities not employed by New York City in 1990, such as preprocessors and large in-vessel composting facilities.

To provide data about facility operations four teams of consultants were employed for each of three types of facilities:

- Recycling facilities, including preprocessors
- Composting facilities, including that for dredge spoils
- Transfer facilities
- Landfills
- Municipal waste combustors, including those for medical waste.

Literature review of existing facilities provided data about equipment costs, expected diversion rates and acceptable levels of contamination, required staff levels, and all other variables associated with constructing and operating these facilities.

Because the modeled facilities were generic facilities, the data developed was not site-specific but was generalized to match conditions as were generally found in New York City. For example, some construction activities, such as grading, are site-specific and could be considered only generically. This is reflected in the cost structure of these generic facilities, in which a standard per acre cost was assigned based on general conditions in New York City. Actual costs for grading a specific site in preparation for construction will vary depending on the site's geology and whether or not existing structures stand on the site.

Because facility construction and operating cost data was developed from data specific to New York City (where costs are generally higher than in many places in the country), many of the listed facility costs are unique to New York City conditions. This includes land costs, construction costs, and labor costs. However, much of the rest of the facility data, such as equipment costs and operating parameters, can be more generally applied to similar facilities in other locales.

Once the collection of waste was modeled by **WastePlan** it was routed to the appropriate facilities. Based on the nature of each facility and its modeled operating parameters, some waste was diverted to market, and the rest was passed through as residue. Unless the facility in question was a landfill, residue was routed to a second facility. All residue and waste remaining after processing must end up in one of two locations in **WastePlan**: a landfill or on a truck to be exported from the City. All mass balances were maintained in the planning process. Every ton of waste collected is accounted for in one of four locations:

- The marketplace (products from recycling and compost facilities, including preprocessors, or salable energy from municipal waste combustors)
- The atmosphere (resulting from volatilization from composting facilities or municipal waste combustion)
- A landfill (including both solid waste landfills and ashfills)
- Outside of the city through export.

WastePlan Planning--The Iterative Process

The development of the New York City Solid Waste Management Master Plan resulted in four final collection and processing scenarios, known as Scenarios A, B, C, and D, from which a final plan was molded and reported in the New York City Solid Waste Management Master Plan and Generic Environmental Impact Statement. We provide a brief overview of these four scenarios in a later section. These scenarios represented the culmination of almost two years of gathering and refining information and testing and analyzing different options for the collection and processing of all solid waste generated in New York City. The process that lead to the development of these final scenarios was iterative, passing through three distinguishable stages.

The **initial stage** in the development of the plan was performed at a gross level. Analysis was carried out at a borough level; each borough was subdivided into the four residential sectors. Neither institutional nor commercial waste was considered at this initial stage, nor were the five special waste streams. Thirteen separate scenarios were tested at this gross level. Though they could not provide reliable cost and operating conditions, they provided relative cost information and provided and informed future decisions about what collection and processing options merited further testing and analysis.

The analysis was carried out at this gross level to facilitate the management of both the data entered into the model and to curtail the output to be analyzed. At this stage in the process, numerous analyses were conducted to test the sensitivity of overall costs to changes in variables such as: recycling diversion rates, vehicle collection efficiencies, labor costs, and export costs.

The **second stage** in the analysis was a refinement of the first stage -- the addition of commercial and institutional wastes, again at a gross level. Institutional and commercial subsectors were grouped according to the types of programs each could support, including: paper recycling, high quality recycling and source-separated organics recycling. Better data was applied and several likely collection and processing scenarios were tested and analyzed in greater depth in preparation for the final stage of the plan's development.

In the **third and final stage**, collection programs were designed specifically for each of the city's 59 sanitation districts, 12 sanitation zones, and five boroughs. The data developed in the baseline analysis pertained to the four levels of residential housing density in the city. Each of the 59 sanitation districts contained a mix of these four residential densities; the density-specific parameters were weighted by the proportion of each housing density found in a sanitation zone to create a unique set of collection parameters for each sanitation zone. Other zone-specific parameters were applied such that a unique set of collection programs was operated in each sanitation zone.

At this final stage, collection and processing information for the institutional and commercial and special waste streams was further refined. Institutional and commercial waste was apportioned throughout the five boroughs, and collection programs targeting recyclables, compostables and refuse were created for each subsector. Data about the special waste streams were incorporated into the model in order to account for all wastes generated in the city.

Whereas previous scenarios used facilities without any particular location and assigned generic travel distances to them and between them, the final stage assigned specific facility locations. This assignment was based on a study of likely site locations within each borough. This allocation allowed the further refinement of creating waste sheds and routing collection programs to specific facilities. This allowed for the assignment of unique travel distances to the facilities and also unique transfer distances for the transport of waste between facilities.

The result of this process was a plan for the management of solid waste in New York City, based on an exhaustive search for and refinement of data, that was developed to a level of detail that promotes great confidence as the city proceeds toward the plan's implementation.

Description of the Four New York City Solid Waste Management Scenarios

Four **WastePlan** scenarios -- Scenarios A, B, C, D -- were developed to model options for solid waste collection and processing systems to manage New York City's projected waste stream over the period 1990 - 2010. Three scenarios included waste combustion; one was a non-combustion scenario. Our analysis models the energy requirements of each of the four scenarios in the year 2000.

A total of 13,323,320 tons of waste are projected to be generated annually by New York City in 2000, but the actual number of tons handled in each scenario varies slightly from this number depending on the quantity of ash generated in each scenario. Residues resulting from recycling and composting facilities are not treated as additional tons generated in the system; total tons handled by these processing facilities is directly equal to residue tons handled plus recovered tons handled. Scenarios A, B, C, D model the collection and disposal of approximately 7,911,600

tons of residential, institutional, and commercial waste in the year 2000. All scenarios also include a projected waste stream of special wastes -- sludge, harbor dredge and debris, medical waste, and construction and demolition waste. These special waste streams constitute 42% of the waste handled in New York City, totalling 5,593,320 tons in the year 2000. We assume that the special waste streams are identical and will be handled in the same way in all scenarios.

Description of the Municipal Solid Waste Stream: Residential, Commercial, and Institutional Waste Sectors

New York City's residential sector is divided into four housing density sectors, each with its own unique collection system characteristics. The four density sectors are characterized as: low density, medium density, high density, and containerized waste in high density areas. Each scenario is a combination of a collection and facility modeling segment and an analysis of the collection, processing and disposal of special wastes. All residential wastes are modeled as collected by the public sector and all commercial wastes (including the construction and demolition waste stream) are modeled as being collected by the private sector. Sewage sludge is a public waste, though its collection was not modeled as it is not the responsibility of the DOS. Institutional wastes and the three remaining special waste streams are collected by a combination of public and private carriers. The four waste management plan scenarios under consideration by New York City are described below.

Table 2-1 presents tons and percent of MSW stream handled by recycling, composting, combusting, landfilling, bulk recycling, and export.¹⁰ Residuals from recycling and composting facilities are sent to landfills and are counted in the landfill percentage. Tons of municipal waste combustor ash generated are sent to an ash landfill in each scenario and appears as the entry under ash landfill. Ash landfill is counted in the calculation of Table 2-1 percentages for the purpose of presenting the total number of tons managed in each scenario, where tons managed includes tons generated plus ash generated. However, we have not included ash landfill or export in our scenario descriptions below that describe the management of the generated tons.

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¹⁰ The total tonnage of materials handled at individual processing and disposal facilities within each scenario varies as a result of the unique configuration of solid waste processing and disposal facilities within each scenario. This, in turn, results in varying levels of residuals that in effect are double-handled at both processing and disposal facilities, causing the total number of tons managed to vary from scenario to scenario.

Scenario A

Scenario A handles 7,729,023 tons of generated MSW by composting 7%, recycling 34%¹¹, combusting 46%, and landfilling 13%. An additional 516,000 tons are ash landfilled in this scenario, and a trivial amount of waste is exported. In this scenario residents are required to separate their trash into three different bags, which are collected in two types of trucks, one with dual-compartments and one with a single compartment. The dual compartment compactor is used to collect recyclable with one compartment for containers and the other for paper materials. The single compartment compactor is used to collect garbage.

High-Quality Materials Recycling: The residential and institutional sectors have source separated collection of high quality materials, which include: all dry paper (except non-corrugated cardboard), textiles, metals, glass, and plastics. The collected materials are processed at material recovery facilities and commercial mixed waste and paper processing facilities.¹² Residue from these facilities is landfilled.

Bulk Recycling: A small quantity of residential bulk materials comprising 2% of the waste stream are collected in a separate bulk collection program. This material is collected and processed by private scrap dealers, not by the DOS. Therefore, we include this waste stream in our accounting of waste generation and management, but do not model the energy needed to collect or process bulk recyclables.

Leaf and Yard Waste Composting: In this scenario, there is an assumed six-week-per year curbside collection period for leaf and yard wastes from the low-density residential sectors. About 5% of the residential waste stream is targeted in this program. Leaf and yard wastes are composted in windrow composting facilities. Residue from these facilities is landfilled.

Organics Composting: Composting is a low priority in this scenario. Selected institutional sectors (e.g., schools, hospitals/nursing homes, correctional facilities) have source separated collection of organic materials, which are then processed at in-vessel composting facilities. Overall, only 7% of the municipal waste stream is composted, including materials collected for leaf and yard waste compost. Residue from these facilities is landfilled.

Waste-to-Energy: All non-recycled and non-composted waste in the residential and institutional sectors is combusted in upgraded existing municipal waste combustors

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¹¹ Includes 2% bulk recycling.

¹² As described in footnote 1, commercial mixed waste and paper processing facilities are designed to capture recyclable materials from the commercial waste stream. These facilities appear in all scenarios.

(retrofitted with energy recovery systems and front end preprocessors¹³) and new waste-to-energy facilities also complete with front end processors (with the exception of the Brooklyn Navy Yard Municipal Waste Combustor¹⁴). The ash residue resulting from this process is disposed in an ash landfill.

Scenario B

Scenario B consists of a plan to manage the 7,729,023 tons by composting 15%, recycling 34%¹⁵, combusting 40%, and landfilling 11%. An additional 490,699 tons of municipal waste combustor ash are ash landfilled. In this scenario, households separate their trash into four categories. Each type of waste is collected by a dual compartment truck, which facilitates the collection of two types of waste at the same time. One dual-compacting truck collects garbage and compostable organic materials, the other dual-compactor collect containers and recyclable paper materials.

High-Quality Materials Recycling: Scenario B has the same high-quality materials recycling program, commercial mixed waste processing program, and bulk recycling program as Scenario A.

Organics Composting: Scenario B has the same source separated collection of organic materials from the institutional sector as in Scenario A. In addition, Scenario B also has a source-separated collection program for residential organic waste. However, there is no separate residential leaf and yard waste collection program. All of the collected organic materials are processed at in-vessel composting facilities.

Waste-to-Energy: The remaining "dry" waste stream (all non-recycled and non-compostable waste) is incinerated at municipal waste combustion facilities as in Scenario A. The waste entering the combustion facilities in this scenario has a considerably higher Btu content then in the other three scenarios due to the drier waste stream. Yet, since such a large portion of the waste stream is diverted to recycling and composting, combustion facilities have a lower throughput in Scenario B. As in Scenario A, all combusted waste is handled in upgraded existing or new combustion facilities. The ash residue resulting from this process is disposed at an ash landfill.

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¹³ Preprocessors refer to facilities called Mixed Waste Processing Facilities (as distinguished from Commercial Mixed Waste Processors) in Appendix II-C and II-E. The preprocessors were modelled as separate facilities from the waste-to-energy facilities to facilitate easier tracking of materials in the analysis, but they are not in fact separate facilities. Pre-processors are designed to capture and process recyclables from the waste stream that are missed by source separation collection programs.

¹⁴ The Brooklyn Navy Yard Incinerator is referred to in Appendix II-E as BNY.

¹⁵ Includes 2% bulk recycling.

Scenario C

Scenario C is unique among the four scenarios in that there is no combustion. Of the 7,729,023 ton generated waste stream, 35%¹⁶ is recycled, 39% is composted, and 26% is landfilled. The same collection system is used as in Scenario B, with households dividing their waste into four separate waste categories, but facilities called "mixed waste processors"¹⁷ are used in place of municipal waste combustors, and all trash that cannot be recycled or composted is landfilled rather than burned. The high quantity of compostable materials results from the mixed waste processing/compost facilities, which target all organic mixed waste as opposed to the source-separated organic materials targeted in the other scenarios.

Scenario C is identical to Scenario B except for the one modeling assumption that the remaining dry waste stream (all non-recycled and non-compostable waste) is processed at mixed waste processing/composting facilities instead of waste-to-energy facilities, and that material which cannot be composted is landfilled rather than burned.

Scenario D

Scenario D is quite different from Scenario C in that it has the highest combustion rate of all scenarios. In this scenario, 65% of the 7,729,023-ton waste stream is combusted, 22% is recycled¹⁸, none is composted, and 13% is landfilled. An additional 747,352 tons are ash landfilled and 53,658 tons are exported. Households are not required to separate waste in this scenario, and all trash is picked up by one set of single-compartment trucks.

Scenario D has the same residential bulk recycling and commercial recycling programs as Scenario A. All non-recyclable waste is burned in three upgraded municipal waste combustors with energy recovery systems, or in new waste-to-energy facilities. Waste is not preprocessed before combustion takes place.

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¹⁶ Includes 2% bulk recycling.

¹⁷ In this scenario, an additional residential mixed waste processing/composting component is designed to sort out and process recyclable and compostable materials from a mixed waste stream. The mixed waste processors in this scenario act as a substitute for municipal waste combustion facilities in other scenarios.

¹⁸ Includes 2% bulk recycling.

Description of the Five Special Waste Streams Modeled in Each of the Four Scenarios

Each of the four scenarios also includes five special waste streams: 1) construction and demolition debris; 2) sewage sludge; 3) medical waste; 4) harbor debris; and 5) dredge spoils. Each of these special waste streams, totalling 5,593,320 tons in all, are collected and processed the same way in all four scenarios. Table 2-2 presents tons of special wastes handled by recycling, composting, combusting, landfilling, ash landfilling, bulk recycling, and export.

Construction and Demolition Debris. In all scenarios in the year 2000, 2,494,738 tons of construction and demolition debris will be collected in 40-cubic-yard roll-off trucks and delivered to construction-and-demolition- debris (C&D) processing facilities, where about half of the delivered material will be recovered for recycling. At the C&D processing facilities, large pieces of ferrous and non-ferrous metal, cardboard, and wood are placed into containers. The inorganic materials including concrete, rocks and bricks are further processed in a rock-crushing and screening system. The wood component of the waste stream is sent to a wood chipper or shredder. Thus the primary recyclables include wood,¹⁹ which is processed into chips; concrete/rocks/bricks, which are processed into inorganic fill and aggregate; and ferrous metals, which are processed for shipment to recycling plants. The resulting residue from the processing facilities is landfilled.

Sewage Sludge. Only the processing and disposal of sewage sludge are modeled in the scenarios; the collection and transport of sewage sludge is not considered since this is not a responsibility of the New York City DOS. In the year 2000, the proposed sludge management program would consist of two chemical stabilization plants, one dry pelletization plant, and seven sludge-composting facilities, which will handle 205,886 tons of sludge per year. Sludge residues are landfilled.

Medical Waste. The medical waste stream includes all regulated medical waste generated in New York City. The red-bag waste is collected by licensed medical-waste carters. Of the total regulated medical waste handled in the scenarios, 11% is recycled at materials recovery facilities, 14% is composted, 62% is burned at either a regional or on-site medical waste incinerator or pathological waste incinerators, and 13% is landfilled. All of the landfilled material is residue from the recycling, composting, and incineration processing facilities.

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¹⁹ The majority of the wood waste generated in New York City (76%), is generated as construction and demolition debris (C&D). The 718,628 tons of wood waste generated by this sector comprises approximately 29% of the C&D waste stream. From an electricity generating standpoint, this could be an important source for energy planning purposes. We assume 100% of recovered wood waste is assumed to be combusted in separate wood boilers. The energy generated from this combustion is discussed in Section 4.

Table 2-1. Tons of Municipal Solid Waste From Generation and Combustion Residues Managed in Scenarios A,B,C, and D [1].

	Scenario A		Scenario B		Scenario C		Scenario D	
	(tons/year)	(%)	(tons/year)	(%)	(tons/year)	(%)	(tons/year)	(%)
Recycling [2]	2,453,237	32%	2,480,985	32%	2,519,658	33%	1,518,406	20%
Composting [2]	543,355	7%	1,127,518	15%	2,974,498	39%		0%
Combustion[3]	3,525,746	46%	3,090,806	40%		0%	4,992,051	65%
Landfill [4]	1,018,410	13%	846,778	11%	2,048,121	26%	989,156	13%
Ash Landfill	513,780		490,699				747,352	
Bulk Recycling	182,665	2%	182,665	2%	182,665	2%	182,665	2%
Export	5,241				4,081		53,658	
Total Tons [5]	8,242,434	100%	8,219,451	100%	7,729,023	100%	8,483,288	100%

[1] Includes residential, institutional, and commercial waste.

[2] Does not include residue.

[3] Includes total tons received at facility.

[4] Includes residues from recycling and composting facilities.

[5] Total tons vary across scenarios owing to varying rates of ash generation.

Table 2-2 Tons of Special Wastes Managed in Scenarios A,B,C, and D [1].

	Recycling (tons/year)	Composting (tons/year)	Combustion (tons/year)	Landfill (tons/year)	Ash Landfill (tons/year)	Export (tons/year)	Total (tons/year)
Sludge		184,042		21,844			205,886
Harbor Dredge		29,805				2,602,261	2,632,066
Harbor Debris	848		21,874	727	585	4,750	28,784
Medical Waste	27,458	35,384	159,345	10,244	23,450		255,881
C & D	1,246,246		[2]	1,248,492			2,494,738
Totals	1,274,552	249,231	181,219	1,281,307	24,035	2,607,011	5,617,355

[1] Special waste streams are managed the same way in each scenario.

[2] Wood waste combustion is treated separately in Section 4 of this report.

Harbor Debris. In the proposed harbor debris management program, in the year 2000, an estimated 3% of this material -- floatables -- would be collected by skimmer boats and landfilled at Fresh Kills; 76% would be collected through the shoreline pier-removal program and incinerated after shredding and material recovery at a municipal waste-to-energy facility; and the remaining 17%, the amount projected to be collected on New Jersey beaches in that state's shoreline clean-up program, would be disposed of outside the City.

Dredge Spoils. In the proposed dredge-spoils-management program, the DOS will dredge an estimated 1% of the total amount of material that will be dredged from the New York Harbor. It will de-water these 29,805 tons for use as landfill cover. All other material dredged from the Harbor will be disposed of at sea under the Corps of Engineers' auspices, or at upland locations outside the City.

Application of Energy Data to the New York City Solid Waste Management Plan²⁰

Two general types of data are required to conduct the energy analysis of the solid waste management system. The first, described in Step 1 of the Analytical Approach, is the solid waste system data. This information was developed for this case study using **WastePlan**, in the course of producing the New York City planning scenarios.

Energy use and recovery data, discussed in Step 2, were extracted from an extensive solid waste management database created for the New York City solid waste planning project. Energy data, along with cost, environmental, and siting data for numerous facilities, waste collection and transfer vehicles, were developed by a team of project consultants. Six technology consultants, one each for every management strategy (recycling, composting, combustion, transfer, landfilling, and export), developed data for each facility and vehicle, appropriate to their area of expertise. Thus, for example, the recycling consultant developed data for all recycling facilities and vehicles.

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²⁰ Readers not interested in further methodological detail may wish to skip the following two sections and proceed to Section: Results of the Energy Analysis.

Collection system data such as vehicle capacity, compaction factors,²¹ fuel efficiency, and other relevant data were developed based on information provided by the DOS as well as the technical consultants. A full description of the assumptions and methodology used for developing the respective GEIS collection system analyses for each scenario is presented in Appendix II-A. Table 2-3 contains a list of the types of collection and transfer vehicles modeled in the GEIS planning process.

The technology consultants developed a Reference Facility Design Sheet for all facilities. These sheets contain design and engineering information, including site layout and process schematics, type of pollution control equipment, hours and days of operation, tonnage throughput, operating to design capacity ratios, etc. Appendix II-C contains Solid Waste Management Facility Data Sheets with design information and energy use data for the 32 types of solid waste management facilities used in the New York City scenarios.²² Table 2-4 contains a list of the facilities included in Appendix II-C.

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²¹ Compaction factors for all vehicles are based on an extensive compaction study conducted by the DOS, as indicated in: New York City Department of Sanitation, GEIS Draft Appendix Volume 1.2, Waste Stream Data Compaction Study, 1992. The data indicated an average compaction rate of 3:1 for recycling vehicles, which assumed the paper side of the co-collection vehicle compacting at a rate of 2:1, and the container side compacting at a rate of 4:1. The derivation of these compaction ratios is described in full detail in Appendix II-A. Some sources, such as Bill Davidson of the Northeast Maryland Disposal Authority, suggest that compaction at a rate of above 1.5:1 causes glass breakage and thus the DOS value may be too high. Nevertheless, the decision to use the New York City data was based in the fact that the information was primary data from DOS field studies. Future analysts should make adjustments appropriate to their locales.

²² Notes on Solid Waste Management Facility Data Sheets in Appendix II-C:

1. Average Annual Throughput (tons) is calculated by multiplying Daily Throughput (tpd) by Days/year and Availability (%).
2. Energy Used values are based on Average Annual Throughput.
3. Average Btu/ton is calculated by dividing Total Btu for Facility by Average Annual Throughput.
4. Codes used for Energy Type are as follows: E for electricity, D for diesel, G for natural gas, N/A indicates that data were unavailable.
5. The operation of the facility is described in the Facility Description section and energy-using operations are described in the Energy Use section.

Table 2-3. Vehicles Included in the New York City Solid Waste Planning Scenarios.

Collection Vehicles:

Automatic EZ Pack
Manual Rear Loader-Dual Compact
Manual Rear Loader
Commercial Front Loader
Roll On/Off Manual Truck

Transfer Vehicles:

Barge
Roll On/Off Manual Truck

Note: See Appendix II-D and II-E for more detail on vehicle specifications and usage by Scenario.

The technology consultants developed the facility/collection design and energy use data for the reference facilities and vehicles using both engineering design estimates and energy consumption data for existing facilities and vehicles. These data were then used for comparison of cost, environmental, socioeconomic, and energy impacts of alternative scenarios. Because these data were developed for so-called "reference", or generic facilities, they are not suitable for facility design purposes. Instead, they represent in many cases a composite facility appropriate to the level of detail required in a master planning process.

Table 2-4. Facilities Included in the New York City Solid Waste Planning Scenarios.*

Materials Recovery Facility
Commercial Paper Processing Facility
Materials Buy Back Facility
Materials Drop-off Facility
Waste Oil Facility
Waste Tire Facility
Household Hazardous Waste Drop-off Facility
Mixed Waste Processing Facility (Organics, Scenario C)
Mixed Waste Processing (No Organics-Scenarios A,B,D) Facility
Commercial Mixed Waste Processing (Recyclables)
Residential Mixed Waste Composting/Processing Facility (Scenario C)
In-Vessel Compost (Source Separated Organics) Facility
Leaf and Yard Waste Composting Facility
Sludge Composting Facility
Sludge Pelletizing Facility
Sludge Chemical Stabilization Facility
Construction and Demolition Debris Processing Facility
Harbor Debris Processing Facility
Dredge Spoils Dewatering Facility
Truck Transfer Station
Rail Transfer Station
Marine Transfer Station
MSW Mass-Burn Combustor
MSW Refuse Derived Fuel Combustor
MSW Modular Combustor
Regional Pathological Combustor
Regional Medical Waste Combustor
On-Site Medical Waste Combustor
Sludge Combustor
Sludge/MSW Landfill
Ash Landfill

* Note: see Appendix II-C and II-E for detailed facility descriptions and energy specifications by facility.

Methodology for Energy Analysis of Solid Waste Management Planning Scenarios

The energy requirements in each scenario are broken into four components:

- collection
- transport/transfer
- processing and disposal (energy used at facilities)
- energy generation (at municipal waste combustors and landfills).

The first component, **collection**, consists of the quantity of energy used by waste collection trucks. Collection trucks collect waste from the point of generation (e.g., a residence), and transport the waste to either a transfer facility or a processing facility. **Transport/transfer**, accounts for energy used to transfer materials between the processing facilities and their final disposal destinations. The **processing and disposal** component accounts for energy used at waste processing and disposal facilities. **Energy generation** accounts for the gross electricity and steam that is generated at the waste to energy facilities and the methane that is recovered at the municipal solid waste landfills.

The energy requirements for each of the four components were calculated using several spreadsheets designed for two tasks: a) to calculate total quantity of energy for collection, processing and disposal (facility operation), energy recovery from municipal waste combustors and landfills, and transfer for all waste; and b) to allocate the energy for the four system components to five waste management programs: recycling, composting, combustion, landfill, and bulk recycling. This allows a comparison of the average Btu/ton energy intensity for these management strategies.²³ The allocation is conducted using output data from **WastePlan** scenario

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²³ This allocation was performed for cost, environmental, and socioeconomic impacts.

runs. These spreadsheets are presented in Appendix II-E²⁴ for each of the four scenarios, in the following order:

- Residential Collection
- Commercial Collection
- Institutional Collection
- Special Waste Collection
- Facility Energy (Processing and Disposal)
- Energy Recovery
- Facility Energy Summary
- Transfer Energy
- Energy Summary

The following sections describe the methodology for calculating the energy impacts for each of the four system components.

Collection. The New York City planning scenarios model collection systems for the following waste streams: residential, institutional, and commercial, which together comprise the municipal solid waste stream, and five special waste streams (construction and demolition, regulated medical waste, dredge spoils, harbor debris, and sewage sludge). All solid waste generated in New York City is accounted for in the collection programs. Of these waste streams, only the residential sector is wholly collected by the public sector. The institutional sector is collected by both the public and private sectors, and the commercial sector is collected wholly by the private sector. Of the special waste streams, harbor debris and sewage sludge are generally collected by the public sector. Dredge spoils are collected by many different entities including the Department of Sanitation, the Army Corps of Engineers, and numerous private entities. Regulated medical waste is collected by the private sector. The collection energy spreadsheets calculate the total amount of energy required to collect all of these waste streams, and to allocate the energy to recycling, composting, combustion, and landfilling.

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²⁴ The following conversion factors were used to convert energy use and energy generation into units of Btus:

Oil (Residual)	149,700 Btu/gallon
Diesel Fuel	138,700 Btu/gallon
Gasoline	125,000 Btu/gallon
Natural Gas	1,031 Btu/cubic foot
Coal	25,000,000 Btu/ton
Electricity Use	10,500 Btu/kWh
Steam	1,350 Btu/lb.

These conversion factors were used throughout this study. See Table 3-3 for sources.

Summary Table 2-7 presents the gallons of fuel and the Btu content of the fuel used for each collection scenario by waste management option. The collection energy spreadsheets in Appendix II-E list the average material densities collected in each truck by collection program. We assumed that every truck runs 5.25 hours per day and consumes 1 gallon of fuel per hour.²⁵ Thus, total fuel use per day is modeled at 5.25 gallons per day per truck. Gallons of fuel consumed is produced when this figure is multiplied by the number of trucks on the road each day.

The determination of the number of trucks required for any one collection program is performed by the WastePlan computer model based on values for more than 16 different variables entered into the model, as displayed below in Table 2-5. A detailed discussion of these variables and the methodology used to derive values for them can be found in Appendix II-A.²⁶

²⁵ The New York Solid Waste Management Master Plan and Generic Environmental Impact Statement indicates that a value of 4 gallons per hour was used in developing the master plan. Subsequent data indicates that the Department of Sanitation spent \$1.844 million on diesel fuel for its collection fleet in fiscal year 1990. At an average cost of \$0.93 per gallon, this results in 1.98 million gallons being consumed. When this is applied to the 1,189 daily truck shifts that operated by the DOS in 1990 at an assumed 5.25 hours per day, a per hour fuel use figure of approximately 1.0 is the result.

This figure of 1 gallon of fuel consumed per hour of vehicle operation produces a mile per gallon figure that ranges from 2.6 to 8.0 miles per gallon, depending on type of truck employed. These figures are more in keeping with fuel efficiencies for refuse collection vehicles as reported by vehicle manufacturers.

²⁶ Two equations are important in the derivation of the number of trucks on the road during the course of a collection day: one calculated loads per truck per day, the other calculates the trucks per day. Those two equations are displayed below.

$$LPD = \frac{CH}{\frac{cr \times C \times AU \times sof \times P \times w \times PU \times d}{sph \times AU_s \times G \times dv} + 2 \frac{dist}{mph} + q} + \frac{CH - 2 \times (2 \frac{dist}{mph} + q)}{\frac{cr \times C \times AU \times sof \times P \times w \times PU \times d}{sph \times AU_s \times G \times dv}} - 1$$

and

$$TPD = \frac{G \times dv}{LPD \times d \times w \times C \times cr \times D}$$

For a full discussion of how these equations were derived and the definition of all variables used in these equations, see Appendix II-A.

Table 2-5. WastePlan Collection Variables.

Symbol	Definition
CH	total collection hours per day
cr	compaction ratio of the collection vehicle
C	useable vehicle capacity
AU	total activity units targeted
sof	set-out rate for targeted materials
P	highest participation rate
w	collection weeks per year
PU	collection pick-ups per week
d	(aggregate) density of collected materials
sph	stops per hour made by truck
AUs	activity units per stop
G	tons of (targeted) waste generated
dv	diversion rate for (targeted) waste
dist	distance vehicle must drive to drop-off
mph	speed at which vehicle travels to drop-off
q	total vehicle queuing and unloading time
D	number of collection days per week

Differences in truck collection efficiencies arise from four main sources:

- the density of the sector being serviced, which affects the rate at which materials can be collected;
- the types of material targeted for a collection program;
- the type of vehicle employed for the collection program; and
- the distances to be travelled by the truck both on-route and in delivering collected materials to a drop-off location.

The type of materials targeted for a collection program affect the amounts that can be collected per day of operation. Some materials, such as plastics, have a lower density and require more space in a truck than other higher density materials such as office paper. Similarly, the vehicle employed and its: speed travelling through its

district; compaction ratio and useable volume all affect how much can be collected by any one vehicle in a day and thus the total number of vehicles required.

All collected materials are categorized as either recyclables, compostables, or garbage, based on how they are processed, and we track the energy associated with the collection of each of the three components. Depending on the amount of material combusted in each scenario, the "garbage" collection energy is distributed between landfill and municipal waste combustor tons.

An estimate of the energy required for collection of each of the three waste categories is listed at the bottom of the collection sheets in Appendix II-E, as well as a tally of the total number of trucks required in the scenario. Because all trucks are modeled with the same daily fuel usage,²⁷ scenarios requiring the same number of trucks will have identical collection energy requirements. However, the distribution of this required energy among recyclables, compostables, and garbage may differ depending on the annual total quantity of materials collected within each respective collection program. As noted above, the total quantity of materials collected by any one truck will be affected by a number of different variables.

Observing Table 2-7, we can see that Scenario C has the most energy intensive collection efforts which is due primarily to the need to collect compostables separately.

Transport/Transfer. Table 2-8 provides fuel consumption information and the energy used in transport operations for each of the four scenarios. The Transfer Energy values listed in Appendix II-E identifies the energy needed to transfer the recyclables, compostables, and garbage destined for combustion and landfiling between the processing facilities and their final disposal destinations. For the purpose of counting the energy associated with each type of processing facility, the energy necessary to transfer residues to landfills has been charged against the facility generating the residue. Both truck transfer and barged transfer were considered in this analysis. Scenarios C and D used the most fuel, or energy, to transport materials. In Scenario C the reason for the high fuel use stems from the high percentage recycling and composting residues, resulting in a large number of barge trips. In Scenario D, the high energy use is a result of the large recycling and combustion residues, and this results in many more truck transfer miles and a few more barge trips than we see in Scenarios A and B.

Detailed transfer distance analyses were performed in conducting the New York City solid waste management planning process. Distances between sending and receiving

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²⁷ According to DOS and a variety of truck manufacturers, the total fuel usage/hour by solid waste collection vehicles does not vary significantly between collection vehicles. Factors such as traffic conditions, housing density, etc. tend to have a greater influence on hourly fuel usage by collection vehicles.

facilities were measured and used to calculate annual distances travelled in transferring residue and waste from one facility to another. The appropriate method of transfer -- truck or barge -- was assigned to each facility. The results of this analysis in terms of truck and barge transfer miles per day are presented in Table 2-6, below.²⁸

Daily truck miles were multiplied by the 302 transport days per year used in the NYC GEIS study to produce annual truck miles. We used a figure of six miles per gallon to calculate total gallons consumed.²⁹

Table 2-6. Daily Average Transfer Miles in NYC GEIS.

Scenario	Truck Transfer Miles per Day	Barge Transfer Miles per Day
A	3,165	240
B	2,766	243
C	1,347	366
D	4,637	257

²⁸ See Appendix II-B for a discussion of the methodology used in the New York GEIS study to determine transfer in all four scenarios.

²⁹ This value for fuel efficiency is based on a study by the Oak Ridge National Laboratory, which reported an "energy intensity" for heavy trucks of 23,075 BTU per vehicle mile. This corresponds to six miles per gallon fuel efficiency.

See: Davis, Stacy C.; Shonka, Deborah, B., et al. Transportation Energy Data Book: Edition 10, Oak Ridge, Tennessee: Oak Ridge National Laboratory, September 1985.

Table 2-7. Fuel Use in the Collection of Municipal Solid Waste and Special Wastes.

	Scenario A		Scenario B		Scenario C		Scenario D	
	Fuel Gallons	Fuel Btus	Fuel Gallons	Fuel Btus	Fuel Gallons	Fuel Btus	Fuel Gallons	Fuel Btus
Municipal Solid Wastes:								
Recycling	1,160,584	1.59E+11	1,160,584	1.59E+11	1,160,584	1.59E+11	467,883	6.41E+10
Composting	201,460	2.76E+10	599,270	8.21E+10	599,270	8.21E+10	0	0.00E+00
Combustion	1,744,526	2.39E+11	1,635,036	2.24E+11	0	0.00E+00	2,481,752	3.40E+11
Landfill	503,650	6.90E+10	448,175	6.14E+10	2,080,292	2.85E+11	492,701	6.75E+10
Ash Landfill								
Special Wastes:								
Harbor Debris	18,075	2.48E+09	18,075	2.48E+09	18,075	2.48E+09	18,075	2.48E+09
Medical Waste	326,359	4.47E+10	326,359	4.47E+10	326,359	4.47E+10	326,359	4.47E+10
Construction and Demolition	3,947,388	5.41E+11	3,947,388	5.41E+11	3,947,388	5.41E+11	3,947,388	5.41E+11
Totals	7,902,041	1.08E+12	8,134,887	1.11E+12	8,131,968	1.11E+12	7,734,157	1.06E+12

Table 2-8. Fuel Use in the Transport of Municipal Solid Waste and Special Wastes.

	Scenario A		Scenario B		Scenario C		Scenario D	
	Fuel Gallons	Fuel Btus	Fuel Gallons	Fuel Btus	Fuel Gallons	Fuel Btus	Fuel Gallons	Fuel Btus
Municipal Solid Wastes:								
Recycling	301,370	4.18E+10	250,901	3.48E+10	281,903	3.91E+10	317,952	4.41E+10
Composting	2,833	3.93E+08	54,146	7.51E+09	202,596	2.81E+10		
Combustion	97,332	1.35E+10	88,681	1.23E+10			172,314	2.39E+10
Landfill								
Ash Landfill								
Special Wastes:								
Sludge	1,738	2.41E+08	1,738	2.41E+08	1,738	2.41E+08	1,738	2.41E+08
Harbor Dredge	2,084	2.89E+08	2,084	2.89E+08	2,084	2.89E+08	2,084	2.89E+08
Harbor Debris	1,738	2.41E+08	1,738	2.41E+08	1,738	2.41E+08	1,738	2.41E+08
Medical Waste	2,257	3.13E+08	2,257	3.13E+08	2,257	3.13E+08	2,257	3.13E+08
Construction and Demolition	83,634	1.16E+10	83,634	1.16E+10	83,634	1.16E+10	83,634	1.16E+10
Totals	492,985	6.84E+10	485,177	6.73E+10	575,948	7.99E+10	581,716	8.07E+10

The calculation to determine gallons of fuel consumed by the tugs pushing the barges was not as direct. The same Oak Ridge study used to determine truck fuel efficiency reported tug fuel efficiency in terms of Btu per ton-miles; 402 Btu per ton-mile are ascribed to tugs.³⁰ An average value of 36 miles per barge trip was calculated from the GEIS report by weighting the distances travelled by all barges by the average number of loads carried by each barge per day. Similarly, an average value of 1,980 tons per barge trip was calculated.³¹ These values were then used to calculate a value of 205 gallons of fuel consumed per barge per trip. From this value, and the average number of barge trips per day, the total fuel consumed by barges was calculated.

Processing and Disposal. The Facility Energy spreadsheets in Appendix II-C calculate the amount of energy used at the processing and disposal facilities modeled in the scenarios. The spreadsheets list the name of the generic facility and the amounts of each type of energy required to operate the facility at its design capacity, for one year. For each facility, all energy types were converted from their natural units, such as kilowatt hours for electricity, to Btus in order to provide a metric for summing the energy impacts. Based on total Btus per year per facility, we calculate an average Btu per ton processed/disposed at that facility. Then, the number of tons of actual throughput is multiplied by the average Btu per ton value to obtain total Btus for the facility. The results of all of these calculations are presented in Appendix II-E and is discussed in detail below.

Energy Generation. The Energy Recovery spreadsheets in Appendix II-E are developed to capture two types of energy generation in the solid waste management system. The first type is energy generated from combustion of waste in a municipal waste combustor (MWC). Municipal waste combustion results in steam production, which may then be converted to superheated steam, electricity, or it may be used as generated. The second type of energy generation that was modeled in this analysis is the generation of methane gas, which results when materials are landfilled. Like steam produced in a MWC, landfill gas may be converted to electricity or high value gas, or used as generated. Since the landfill modeled in the four scenarios is the existing Fresh Kills Landfill, we modeled the production of high value gas, rather than electricity, as this is what Fresh Kills currently produces. The methodology for these analyses are described separately below.

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³⁰Davis et al., op cit.

³¹This is slightly higher than the 1,850 tons assumed per average barge trip as some barges operate 365 days per year and some operate 302 days per year, depending on the facility of origin.

For the purpose of obtaining the most accurate estimate of the electricity generated at a MWC, information from qualified sources provided the important data inputs.³² The generation of steam was analyzed separately from the generation of electricity since this greatly simplified the evaluation of the energy generation, without causing any loss in accuracy. For the purpose of modeling combustion systems, all MWC's were assumed to generate electricity only, with the exception of one plant for which the City expects to have a steam customer. We modeled energy generation for these plants accordingly.

For electricity generation, the energy analysis follows the following formula:

$$(\text{Waste tons-in}) * (\text{Btu/lb waste}) * (2,000 \text{ lb/ton}) = \text{Total Btus into MWC}$$

$$(\text{Total Btus into the facility}) / (\text{Gross heat rate Btu/kWh}) = \text{Gross kWh generated}$$

$$(\text{Gross kWh generated}) * (\% \text{ Internal electric energy use}) = \text{Electric energy used internally}$$

$$(\text{Gross kWh generated} - \text{Internal kWh used}) * (\text{Conversion } 10,500 \text{ Btu/kWh}) = \text{Net total Btus of usable energy generated at facility.}$$

The input values used in these equations are as follows for all MWCs:

Waste tons-in = WastePlan input, varies with scenario

Btu/lb waste = WastePlan input, varies with scenario (averages 5000 Btu/lb)

Gross heat rate = 15,035 Btu/kWh for all RDF and mass-burn waterwall, 18,000 for mass-burn modular incinerators, which are less efficient

Internal energy use = Based on average internal energy use of 13.5% for RDF and 12% for mass-burn facilities

The electricity conversion factor of 10,500 Btu/kWh was determined by the Energy Authority to be a reasonable estimate of the typical heat rate for all types of electric generating facilities to use for computing useable electric energy in terms of Btus. The results of these electricity generation analyses are presented in Table 2-9, below.

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³² Data inputs for this analysis were provided by the Energy Authority after consulting with the American Society of Mechanical Engineers, Wheelabrator Inc., and the Electric Power Research Institute (EPRI). Tellus contacted Ogden Projects, Inc., which provided information that approximated the Energy Authority's in the analysis.

To model the generation of steam from the combustion of waste, we reviewed data on steam-boiler efficiencies provided by the Energy Authority and then examined the information received from Ogden Products, Inc., which concurred with the basic input values put forth by the Energy Authority. For steam generation, the energy analysis follows the following formula:

$$(\text{Waste tons-in}) * (\text{Btu/lb waste}) * (2,000 \text{ lb/ton}) = \text{Total Btus into MWC}$$

$$(\text{Total Btus into MWC}) * (\text{Steam boiler efficiency}) = \text{Steam production in Btus}$$

$$(\text{Steam production in Btus}) / (1350 \text{ Btu/lb}) = \text{Lb of steam out}$$

The input values used in these equations are as follows for all MWCs:

Waste tons-in = WastePlan input, varies with scenario

Btu/lb waste = WastePlan input, varies with scenario (averages 5000 Btu/lb)

Steam Boiler Efficiency = 75% for all MWC except modular, which is 70%

Typical heat value of steam = 1350 Btu/lb

Table 2-9 presents kWhs of electricity and pounds of steam produced in each scenario on an annual basis.

Table 2-9. Gross Electricity and Steam Produced in Each Scenario on an Annual Basis.

	<u>Scenario A</u>	<u>Scenario B</u>	<u>Scenario C</u>	<u>Scenario D</u>
Elec kWh/yr	1.89E+9	1.68E+9	8.86E+7	287E+9
Steam lb/yr	5.09E+9	5.35E+9	0.00E+0	532E+9

The second waste management option that generates energy is landfilling. The exact amount of landfill gas generated by a landfill is not easily predictable as it depends on the amount of waste already in place, the types of wastes in the landfill, and the geology of the site. To make a rough estimate we employed the following equations:

$(\text{Tons/year landfill}) * (2.8 \text{ cf methane gas/lb}^{33}) * (2,000 \text{ lbs/ton waste}) = \text{total cf methane gas}$

$(\text{Total cf methane gas}) * (\text{capture efficiency of wells}) * (\% \text{ Landfill with wells}) = \text{Methane gas captured}$

$(\text{Methane gas captured per year}) * (500 \text{ Btu/cf gas}^{34}) = \text{Btu value of captured methane gas}$

At this point the gas may be used as a low-value fuel, converted to high-value gas (HVG), or converted to electricity. To convert the gas to high-value gas we perform this analysis:

$(\text{Btu value of captured gas}) * (\text{Btu upgrade eff.}) = \text{Btu for HVG}$

$(\text{Btu for HVG}) * (980 \text{ Btu/cf HVG}^{35}) = \text{Total cf of HVG}$

For a detailed description of the results of the landfill gas energy analysis refer to Appendix II-E.

Energy Summary Tables 2-10-2-13 report the total amount of energy used in each scenario, by waste stream and management system component. These tables are based on the data contained in Appendix II-E.

Results of the Energy Analysis

Energy use and energy generation for MSW (residential, institutional, and commercial waste) management for each scenario is summarized in Table 2-14. Net solid waste system energy is calculated by subtracting energy generated from energy used. If a system generates more energy than it uses, it is indicated by a negative number. This, in fact, is the case for all four scenarios.

The energy used by each of the MSW management systems varies from a low of $2.89\text{E}+6$ MMBtus in Scenario C to a high of $5.92\text{E}+6$ MMBtus in Scenario D, and is clearly dominated by the degree of combustion processing technologies utilized in each scenario. The high rate of energy use in Scenario D is a direct result of the high internal electric energy use in combustion, the dominant processing technology

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³³ This value is an average of the range of values (1.6-3.9 cf/ton) cited in Robert K. Ham and Morton A. Barlaz, Measurement and Prediction of Landfill Gas Quality and Quantity, 1987.

³⁴ This value is an average Btu/cf value from the Governmental Advisory Associates, Inc. Methane Recovery from Landfill Yearbook 1988-89.

³⁵ This value is from the Governmental Advisory Associates, Inc. Methane Recovery from Landfill Yearbook 1988-89.

in this scenario. By comparison, Scenarios A and B, with more moderate levels of combustion use $4.71\text{E}+06$ MMBtu/yr and $4.79\text{E}+06$ MMBtu/yr, respectively.

Scenario C relies more heavily on landfilling than all other scenarios. Since energy use in landfilling uncombusted waste is small relative to energy use in municipal waste combustor/ash landfilling operations, energy use in this scenario is very small compared to all others.

TABLE 2-10. SCENARIO A - ENERGY SUMMARY.

Waste Stream	Number of Tons	Collection	Processing	Energy Generation	Transport	Total Disposal	Total Energy	Energy Average Btu/Ton
Recyclables	2,453,237	1.59E+11	7.16E+11		4.18E+10		9.17E+11	3.74E+05
Compostables	543,355	2.76E+10	2.72E+11		3.93E+08		3.00E+11	5.51E+05
Combustibles	3,525,746	2.39E+11	3.15E+12	2.58E+13	1.35E+10		-2.24E+13	-6.35E+06
Landfill	1,018,410	6.90E+10		1.82E+12		1.02E+10	-1.74E+12	-1.71E+06
Ash Landfill	513,780					6.72E+09	6.72E+09	1.31E+04
Bulk Recycling	182,665							
Export	5,241							
Subtotal	8,242,434							
Sludge	205,886		2.13E+12	3.90E+10	2.41E+08	2.18E+08	2.09E+12	1.02E+07
Harbor Dredge	29,805		3.74E+08		2.89E+08		6.63E+08	2.23E+04
Harbor Debris	23,449	2.48E+09	2.17E+10	1.53E+11	2.41E+08	1.49E+07	-1.28E+11	-5.47E+06
Medical Waste	232,431	4.47E+10	1.99E+11	7.96E+11	3.13E+08	4.09E+08	-5.52E+11	-2.37E+06
Construction & Demolition	2,494,738	5.41E+11	8.52E+10		1.16E+10	1.25E+10	6.50E+11	2.61E+05
Dredge Export [1]	2,602,261							
Harbor Debris Export [1]	4,750							
Subtotal	5,593,320							
MSW Subtotal		4.94E+11	4.14E+12	2.76E+13	5.56E+10	1.69E+10	-2.29E+13	Btus
Special Waste Subtotal		5.88E+11	2.44E+12	9.88E+11	1.26E+10	1.31E+10	2.06E+12	Btus
Totals	13,835,754	1.08E+12	6.58E+12	2.86E+13	6.83E+10	3.00E+10	-2.08E+13	Btus

[1] These wastes are part of the New York City generated waste stream. However, they are managed outside New York City, and thus no energy values appear for these waste components.

TABLE 2-11. SCENARIO B - ENERGY SUMMARY.

Waste Stream	Number of Tons	Collection	Processing	Energy Generation	Transport	Total Disposal	Total Energy	Energy Average Btu/Ton
Recyclables	2,480,985	1.59E+11	7.23E+11		3.48E+10		9.17E+11	3.69E+05
Compostables	1,127,518	8.21E+10	5.60E+11		7.51E+09		6.50E+11	5.76E+05
Combustibles	3,090,806	2.24E+11	2.92E+12	2.39E+13	1.23E+10		-2.07E+13	-6.71E+06
Landfill	846,778	6.14E+10		1.51E+12		8.46E+09	-1.44E+12	-1.70E+06
Ash Landfill	490,699					6.41E+09	6.41E+09	1.31E+04
Bulk Recycling Export	182,665							
Subtotal	8,219,451							
Sludge	205,886		2.13E+12	3.90E+10	2.41E+08	2.18E+08	2.09E+12	1.02E+07
Harbor Dredge	29,805		3.74E+08		2.89E+08		6.63E+08	2.23E+04
Harbor Debris	23,449	2.48E+09	2.17E+10	1.53E+11	2.41E+08	1.49E+07	-1.28E+11	-5.47E+06
Medical Waste	232,431	4.47E+10	1.99E+11	7.96E+11	3.13E+08	4.09E+08	-5.52E+11	-2.37E+06
Construction & Demolition	2,494,738	5.41E+11	8.52E+10		1.16E+10	1.25E+10	6.50E+11	2.61E+05
Dredge Export (1)	2,602,261							
Harbor Debris Export (1)	4,750							
Subtotal	5,593,320							
MSW Subtotal		5.27E+11	4.20E+12	2.54E+13	5.46E+10	1.49E+10	-2.06E+13	Btus
Special Waste Subtotal		5.88E+11	2.44E+12	9.88E+11	1.26E+10	1.31E+10	2.06E+12	Btus
Totals	13,812,771	1.11E+12	6.64E+12	2.64E+13	6.72E+10	2.80E+10	-1.85E+13	Btus

[1] These wastes are part of the New York City generated waste stream. However, they are managed outside New York City, and thus no energy values appear for these waste components.

TABLE 2-12. SCENARIO C - ENERGY SUMMARY.

Waste Stream	Number of Tons	Collection	Processing	Energy Generation	Transport	Total Disposal	Total Energy	Energy Average Btu/Ton
Recyclables	2,519,658	1.59E+11	7.32E+11		3.91E+10		9.30E+11	3.69E+05
Compostables	2,974,498	8.21E+10	1.20E+12		2.81E+10		1.31E+12	4.39E+05
Combustibles								
Landfill	2,048,121	2.85E+11	3.36E+11	3.65E+12		2.05E+10	-3.01E+12	-1.47E+06
Ash Landfill								
Bulk Recycling	182,665							
Export	4,081							
Subtotal	7,729,023							
Sludge	205,886		2.13E+12	3.90E+10	2.41E+08	2.18E+08	2.09E+12	1.02E+07
Harbor Dredge	29,805		3.74E+08		2.89E+08		6.63E+08	2.23E+04
Harbor Debris	23,449	2.48E+09	2.17E+10	1.53E+11	2.41E+08	1.49E+07	-1.28E+11	-5.47E+06
Medical Waste	232,431	4.47E+10	1.99E+11	7.96E+11	3.13E+08	4.09E+08	-5.52E+11	-2.37E+06
Construction & Demolition	2,494,738	5.41E+11	8.52E+10		1.16E+10	1.25E+10	6.50E+11	2.61E+05
Dredge Export [1]	2,602,261							
Harbor Debris Export [1]	4,750							
Subtotal	5,593,320							
MSW Subtotal		5.27E+11	2.27E+12	3.65E+12	6.73E+10	2.05E+10	-7.74E+11	Btus
Special Waste Subtotal		5.88E+11	2.44E+12	9.88E+11	1.26E+10	1.31E+10	2.06E+12	Btus
Totals	13,322,343	1.11E+12	4.70E+12	4.64E+12	7.99E+10	3.36E+10	1.29E+12	Btus

[1] These wastes are part of the New York City generated waste stream. However, they are managed outside New York City, and thus no energy values appear for these waste components.

TABLE 2-13.. SCENARIO D - ENERGY SUMMARY.

Waste Stream	Number of Tons	Collection	Processing	Energy Generation	Transport	Total Disposal	Total Energy	Energy Average Btu/Ton
Recyclables	1,518,406	6.41E+10	4.14E+11		4.41E+10		5.22E+11	3.44E+05
Compostables								
Combustibles	4,992,051	3.40E+11	4.94E+12	3.64E+13	2.39E+10		-3.11E+13	-6.22E+06
Landfill	989,156	6.75E+10		1.76E+12		9.88E+09	-1.69E+12	-1.71E+06
Ash Landfill	747,352					9.77E+09	9.77E+09	1.31E+04
Bulk Recycling	182,665							
Export	53,658							
Subtotal	8,483,288							
Sludge	205,886		2.13E+12	3.90E+10	2.41E+08	2.18E+08	2.09E+12	1.02E+07
Harbor Dredge	29,805		3.74E+08		2.89E+08		6.63E+08	2.23E+04
Harbor Debris	23,449	2.48E+09	2.17E+10	1.53E+11	2.41E+08	1.49E+07	-1.28E+11	-5.47E+06
Medical Waste	232,431	4.47E+10	1.99E+11	7.96E+11	3.13E+08	4.09E+08	-5.52E+11	-2.37E+06
Construction & Demolition	2,494,738	5.41E+11	8.52E+10		1.16E+10	1.25E+10	6.50E+11	2.61E+05
Dredge Export	2,602,261							
Harbor Debris Export	4,750							
Subtotal	5,593,320							
MSW Subtotal		4.72E+11	5.36E+12	3.81E+13	6.80E+10	1.97E+10	-3.22E+13	Btus
Special Waste Subtotal		5.88E+11	2.44E+12	9.88E+11	1.26E+10	1.31E+10	2.06E+12	Btus
Totals	14,076,608	1.06E+12	7.79E+12	3.91E+13	8.06E+10	3.28E+10	-3.02E+13	Btus

[1] These wastes are part of the New York City generated waste stream. However, they are managed outside New York City, and thus no energy values appear for these waste components.

**Table 2-14. MSW Management in Scenario A, B, C and D Energy Impacts.
(Million MMBtus)**

ENERGY USE	SCENARIO A (E+6 MMBtus)	SCENARIO B (E+6 MMBtus)	SCENARIO C (E+6 MMBtus)	SCENARIO D (E+6 MMBtus)
Collection	0.49	0.53	0.53	0.47
Processing [1]	4.14	4.20	2.27	5.36
Transport [2]	0.06	0.05	0.07	0.07
Disposal [3]	0.02	0.01	0.02	0.02
Total Energy Used	4.71	4.79	2.89	5.92
ENERGY GENERATION [4]				
Municipal Waste Combustion	-25.80	-23.90	-	-36.40
Landfill Gas	-1.82	-1.51	-3.65	-1.76
Total Energy Generated	-27.62	-25.41	-3.65	-38.16
Net Solid Waste System Energy Use	-22.91	-20.62	-.76	-32.25

- [1] Processing includes energy use at material recovery facilities (MRFs), composting facilities, municipal waste combustors, and mixed waste processing facilities that separate recyclables and organics at the front-end of municipal waste combustors and landfills.
- [2] Transfer includes the transport of residues to the landfill and of ash to the ash landfill. Once again, note that transfer energy is charged to the process that generated the residues needing transfer, not to the destination facility. Hence, the landfill option has no transfer energy charged to it.
- [3] Disposal includes energy use for landfilling MSW and ash.
- [4] Energy generation is expressed using a negative sign for the coefficient.

Since there is small, if any, variation in the configuration/energy use in commercial and institutional waste management systems across scenarios, the differences in MSW collection energy use can be attributed to the design of the residential collection system. Because the collection systems modeled in Scenarios B and C are the same, the energy use values reported for these scenarios are identical. Collection energy use in Scenario D is the lowest because only one truck is used to collect waste from

each point of generation. Two-truck systems were modeled in all other scenarios, however, and the difference in energy use in these systems compared to Scenario D is not significant. The explanation for this lies in the type of truck modeled in the two-truck system. While typical two-truck collection systems utilize a compartmentalized/non-compacting recycling truck and a compacting garbage truck, the New York City two-truck system consists of compacting trucks for recyclables, compostables and garbage. By compacting all waste streams the fuel efficiency (and cost efficiency) of the two-truck systems modeled for New York City is much greater than typical two-truck systems.

Although Scenario D uses the most energy, it also generates the most energy through combustion and energy recovery.³⁶ In Scenario D, the total energy generated is more than six times the energy consumed in all of the solid waste management activities employed in the scenario.

From a net energy perspective, the amount of combustion/energy-recovery is the primary determinant of the system energy balance. All scenarios show a net negative energy balance (i.e., more energy is produced than used) primarily as a result of energy recovery from waste combustion. However even Scenario C, which uses no combustion, generates a modest positive balance from the reclamation of landfill gas alone.

Energy Impacts for Management of Special (Non-MSW) Waste

The energy impacts of the five non-MSW waste streams are detailed in Table 2-15 below. Since the collection, processing, and disposal of these waste streams is identical for all scenarios, the energy data in Table 2-15 applies to all scenarios.

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³⁶ When energy impacts associated with secondary manufacturing are added to the analysis to provide a true systems-wide look at energy impacts from waste management, Scenario D is third most energy efficient out of the four scenarios owing to its relatively low recycling rate (see Table 5-2).

Table 2-15. Energy Impacts of Special (Non-MSW) Waste Streams.

ENERGY USE	Sludge (E+6 MMBtus)	Medical Waste (E+6 MMBtus)	C&D (E+6 MMBtus)	Harbor Debris (E+6 MMBtus)	Harbor Dredge (E+6 MMBtus)
Collection	-	0.04470	0.54100	0.00248	-
Processing [1]	2.13000	0.19900	0.08520	0.02170	0.00037
Transport [2]	0.00024	0.00031	0.01160	0.00024	0.00029
Disposal [3]	0.00022	0.00041	0.01250	0.00001	-
Total Energy Used	2.13046	0.24442	0.65030	0.02443	0.00066
ENERGY GENERATION [4]					
Total Energy Gen.	-0.03900	-0.79600	-	-0.15300	-
NET WASTE STREAM					
ENERGY USE	2.09	-0.55	0.65	-0.13	0.00066
Total Net Energy Use for Special Waste Stream Management					2.06E+ 6 MMBtus

- [1] Processing includes energy use at material recovery facilities (MRFs), composting facilities, municipal waste combustors, and mixed waste processing facilities that separate recyclables and organics at the front-end of municipal waste combustors and landfills.
- [2] Transfer includes the transport of residues to the landfill and of ash to the ash landfill. Once again, please note that transfer energy is charged to the process that generated the residues needing transfer not to the destination facility, hence the landfill option has no transfer energy charged to it.
- [3] Disposal includes energy used in landfilling MSW and ash.
- [4] Energy generation is expressed using a negative sign for the coefficient.

The high-energy use value for sludge is the result of the relatively energy intensive sludge composting process. Processing also accounts for most of the medical and harbor debris waste stream's energy impact. Harbor dredge only accounts for a fractional portion of the energy used by special waste streams because the dredging process is not included in the energy analysis, and most of this material is exported outside of New York City. Overall, the management of the special waste streams presents very minor energy impacts for the total solid waste management system, except for sludge, which has large processing energy requirements.

Conclusion

In this section, we have examined the first of two components of integrated solid waste management, the solid waste management system. In Section 3, we move on to examine the energy impacts associated with the production of products from recycled materials versus virgin materials.

In Section 5, we combine the results of Sections 2, 3, and 4 to give a total accounting of the energy impacts examined in the four scenarios. In preparation for the secondary materials analysis, Table 2-16 lists the tons of 13 categories of recyclable material extracted from each of the four scenarios. While this table reflects the vast majority of recyclables extracted in the scenarios, it is not exhaustive. To keep the analysis manageable, the list does not include mixed plastics and glass, bulk recyclables, textiles, non-bulk ceramics, used oil, tires, and batteries. These materials could be added in future studies.

Finally, note that the totals for recycling in Tables 2-1 and 2-16 are not equal. This is not an error. Table 2-16 includes some wood waste and material from the special waste streams -- e.g., wood waste from the C&D stream -- whereas Table 2-1 includes only those materials recycled in the municipal solid waste stream. Hence, the totals are, by definition, different.

Table 2-16. Recyclables Diverted from the Waste Stream for Scenarios A,B,C, and D [1].

Recyclable	Scenario A (tons/yr)	Scenario B (tons/yr)	Scenario C (tons/yr)	Scenario D (tons/yr)
Paper/Paperboard:				
Corrugated Boxes/Kraft Paper	693,295	693,295	741,576	517,460
Newspapers	351,358	369,888	334,440	140,038
Office/Computer Paper	313,193	316,267	297,886	233,415
Mixed Paper	396,873	401,727	372,880	204,338
Plastics:				
HDPE Containers: clear and colored	78,251	79,649	82,410	31,191
LDPE Films and Bags	32,539	32,539	31,265	1,717
PET Containers: clear and green	32,750	33,199	34,124	12,923
Glass:				
Glass Containers: clear, green, and brown	72,276	74,550	77,996	38,276
Metal:				
Aluminum: cans, foil, misc.	46,245	45,548	45,341	9,712
Steel/Tin Food Containers, Ferrous Scrap	178,559	186,190	203,505	157,753
Miscellaneous:				
Brick/Concrete	555,163	555,163	555,163	555,163
Wood waste [2]	406,521	406,521	406,521	406,521
Total	3,157,023	3,194,536	3,183,107	2,308,507

[1] Recyclables from the MSW stream (i.e., residential, institutional, and commercial streams) except brick/concrete and non-bulk ceramics or batteries.

[2] Wood wastes are assumed to be combusted in special wood waste boilers after separation from the C&D waste stream.

Section 3¹

ENERGY IMPACTS OF VIRGIN AND RECYCLED MATERIALS MANUFACTURING

Energy impacts associated with integrated solid waste management extend beyond the boundaries of the waste management system into virgin and recycled manufacturing systems. This is because materials collected and extracted from the municipal waste stream are used as inputs into secondary materials manufacturing processes. Section 2 focused on the first-order energy impacts of integrated solid waste management: waste collection, transport, and processing. In Section 3, we examine the second-order energy impacts that occur in the manufacturing activities that utilize recyclable materials as well as the virgin systems potentially displaced by this secondary manufacturing. The energy analysis of the solid waste management section tracked energy requirements for recyclables to the point of initial processing at materials recycling facility.

This section picks up where Section 2 leaves off by calculating energy requirements for the transportation of the recyclables to secondary manufacturing facilities, and the production energy used in these processes. We then add the collection and processing energy calculated in Section 2 and compare this secondary manufacturing energy requirement to the total production energy for the same materials manufactured from virgin raw material inputs. Table 3-1 below illustrates the energy data necessary to make this comparison.

The principal objective of this exercise is the development of energy coefficients for thirteen types (or categories) of recyclable materials. These coefficients embody the difference between the energy required to manufacture an intermediate or final product from **virgin** materials and the energy needed to manufacture the same intermediate or final product from **recycled** materials. This energy coefficient may then be used to estimate the energy impact associated with the diversion of each ton of recyclables from the waste stream.

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¹Appendix III corresponds to this section.

To perform this comparative analysis, we make the simplifying assumption that recyclable materials² extracted from the waste stream to produce a certain amount of new product displace an equal amount of virgin-based product. This means that the virgin raw materials required to produce that amount of product will **not** be mined, processed, transported to a manufacturing plant, or processed into product. *Thus, our perspective is the energy impact caused by recycling the ton of recyclables.*

Table 3-1. Energy Data for Comparison of Virgin and Recycled Materials Manufacturing.

Energy Data:	Virgin System	Secondary System
Raw Materials Acquisition Energy	Input materials mining and initial processing	Mining of recyclables from the waste stream, as calculated in Section 2 (i.e., collection and processing materials at MRFs)
Energy for Transport of Raw Materials	Transport of virgin raw materials from mining location to production facility	Transport of recyclables from MRF to secondary processing facility
Production Process Energy	Process energy for virgin production system	Process energy for secondary production system

Given this conceptual framework, we calculate the energy coefficient for all materials as follows:

Energy coefficient (Btu/ton recyclables diverted) =

$$\frac{\text{Btu/ton virgin product} - \text{Btu/ton recycled product}}{\text{tons recyclables utilized/ton recycled product}}$$

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² Recyclable materials tracked through the secondary manufacturing stream are the value-added materials resulting from the separation and initial processing of recyclables at materials recycling facilities. Therefore, they are referred to here as recyclables as opposed to waste.

Note that the energy difference between virgin and recycled production must be divided by the tons recyclables/ton recycled product because the ratio of recyclables to product is not always one to one. For example, it requires 1.11 tons of used beverage cans (UBCs) to produce 1 ton of molten aluminum because used cans contain paint and water, which cannot be turned into aluminum. Furthermore, some of the aluminum is oxidized in the melting furnace. Dividing by the ratio of recyclables to product allows the energy coefficients to be applied to a ton of recyclables diverted from the waste stream (as opposed to a ton of product). In Section 2, mass balances, participation rates, source separation efficiencies, and process efficiencies determine the tons per year of recyclables diverted from the waste stream (see Table 2-16). In the same vein, the denominator in the equation above accounts for mass balance and process efficiencies of the secondary production systems.

The methods for selecting particular virgin and secondary manufacturing systems, and the methodological framework for determining the energy requirements for these systems are discussed in detail in the remainder of this section. In preview of a more detailed discussion, some key assumptions used in the development of the energy coefficients are as follows:

- In the comparison of virgin and secondary systems, we assume closed loop recycling of materials diverted from the waste stream.
- The energy value of fossil fuels used in the production processes is the at-the- nozzle value for the fuel, and does not include energy for extraction, processing, transporting, or precombustion.
- Except where otherwise indicated, electricity is considered to be generated from a generic national average mix, with a fossil fuel heat rate equivalent of 10,500 Btu/kWh. See Table 3-3 for a complete list of the Btu conversion factors used in the manufacturing systems.
- When calculating the energy requirements for virgin and secondary manufacturing systems, we do not include the energy value of raw materials.
- Where technically possible, we calculate the energy required for virgin production system using 100% virgin raw materials and requirements for the secondary system utilizing 100% recyclables as the materials input in the production process.

Due to technical limitations, virgin production of steel and glass includes some recycled material inputs.

- Indirect energy requirements for manufacturing processes, such as operation of pollution control devices, are not included in the energy analysis.
- In the transportation analysis, bulk densities for all materials are assumed to be the same. While this may underestimate the transport energy for the low density plastics, overall energy impacts of transportation are minimal as compared to process energy. Thus this assumption does not significantly affect the results of this study.³

For a given solid waste management system scenario, the energy coefficients can be attached to each ton of material targeted for recycling, and then summed to approximate the second-order energy impacts associated with the recycling program that has been modeled. This approach is illustrated in Section 5 Case Study: New York City in the Year 2000. A description of recyclable materials and their corresponding products is presented below.

The energy coefficient equation represents the global energy impact associated with the use of a ton of recyclable material. In other words, this equation does not address the geographic incidence of the energy impacts -- *where* additional energy will be used in secondary manufacturing, and *where* energy will no longer be used for virgin manufacturing. For example, by applying the energy coefficients to a particular New York City solid waste management plan, one can estimate the total energy impact of the recycling plan. However, this does not reveal where these impacts will occur: in New York City, in New York State, within or outside of the United States. In Section 5, we develop and apply a method for adding spatial dimension to the New York City analysis to assess the geographical incidence of the global energy impacts estimated in the above equation.

RECYCLABLE MATERIALS AND PRODUCTS

The recyclable materials and corresponding products/intermediates examined in this study appear in Table 3-2. The list represents the major categories of materials targeted for recycling in the U.S. today. Recyclable materials are matched to either a final or intermediate product according to several guidelines. These guidelines,

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³ In conversations with several plastics recyclers we were able to obtain cost, not energy, data for transport of baled plastics. One industry contact provided energy data for their entire collection process, but we were unable to disaggregate data for the appropriate transportation link.

detailed below, reflect the principal goals of this study -- to calculate the differences in energy use in virgin versus recycled manufacturing and to determine the spatial incidence of these energy impacts. The special case of wood waste extracted from the waste stream is considered separately in Section 4, because it is assumed that all wood waste is reused as boiler fuel rather than recycled.

The guidelines for matching recyclable materials to a final or intermediate product are:

- **Product can be made from either virgin or recycled materials.** Only final or intermediate products that can be made from either virgin or recycled material are included⁴.
- **Significant end-markets.** While in many cases more than one product can be made from these materials, we have chosen final or intermediate products that are currently significant end-markets for these materials.
- **Energy convergence point.** Since our interest is in calculating the difference in energy use between virgin and recycled manufacturing systems, in some cases we chose to model the production of an intermediate product (rather than a final product). This occurs in cases where no significant difference in energy use exists for the two systems in steps subsequent to intermediate product manufacturing, such is the case with plastics recycling. This energy convergence concept applies to both production process energy and transportation energy.

In the following Methodological Framework subsection of Section 3, we present the framework used to analyze the energy impacts associated with virgin manufacturing and recycling systems.

Note that used lubricating oil may be remanufactured into lubricating oil base stock, and used tires may be combusted to generate energy. An estimated 10.3 million gallons of used motor oil⁵ and 3.5 million tires⁶ are produced each year in NYC.

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⁴ In the case of plastics, we compare the energy used to manufacture virgin and recycled plastic pellets (an intermediate product) rather than a final product, such as a plastic bottle or flower pot. While virgin-based and recycled plastic-based pellets tend to be used to manufacture different final products -- virgin pellets for high-end uses such as plastic beverage bottles and recycled pellets for lower-end uses such as flower pots -- we assume that virgin pellets would be used to produce lower-end final products if recycled pellets were not available.

⁵ Varandani, M., NYCDEP, Nov. 1993.

The energy saved if the waste oil was recycled is approximately .5 million MMBtu/year. If the oil was used as blended fuel, about 1.1 million MMBtu of useable heat would be produced assuming a boiler efficiency of 80%. The energy produced by using the tires as kiln fuel is about 1.2 million MMBtu/year assuming a kiln efficiency of 80%.

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⁶ Moore, G., NYCDOS, Nov. 1993.

Table 3-2. Recyclable Materials and Corresponding Products.⁷

Recyclable	Final Product/Intermediate Product
<u>Paper/paperboard</u>	
Corrugated boxes/kraft paper	Linerboard (for corrugated boxboard)
Newspapers	Newsprint
Office/computer paper	Printing and Writing paper
Magazines/glossy paper/books/ telephone books	Coated folding boxboard
<u>Plastics</u>	
HDPE containers: clear and color	HDPE pellets
LDPE films and bags	LDPE pellets
PET containers: clear and green	PET pellets
<u>Glass</u>	
Glass containers: clear, green, brown	Molten glass
<u>Metal</u>	
Aluminum: cans, foil	Molten aluminum
Steel/tin food containers and ferrous scrap	Molten steel
<u>Miscellaneous</u>	
Brick/concrete	Aggregate road base

METHODOLOGICAL FRAMEWORK

The framework presented in this section is used to estimate the total energy required to manufacture products from virgin materials and recyclable materials. In

⁷ Tire recycling and combustion are growing industries. Currently, more than 20 states have some sort of tire management program. An estimated 25% of all tires in the United States are recycled by retreading. The potential for recycling also exists with rubberized asphalt, which can utilize 16,000 tires per road mile. Tires are also used as a fuel supplement for paper mills, power plants, and cement kilns, each tire comparing to the energy contained in two gallons of oil.

developing this methodology, we were *guided* by a framework developed for life-cycle assessments (LCA) at a workshop sponsored by the Society of Environmental Toxicology and Chemistry (SETAC), in August 1990⁸. LCA is a tool for evaluating the environmental burdens associated with a product, process, or activity. An LCA consists of three stages, as follows:

- Stage 1: Quantifying the energy and material inputs, and associated environmental releases
- Stage 2: Assessing the impact of uses of energy and material inputs and impact of environmental releases
- Stage 3: Evaluating opportunities to reduce energy and material inputs or environmental impacts.

Of specific interest in this study is the framework developed for the first step of the LCA, known as a life-cycle inventory (LCI). The LCI phase quantifies the inputs and outputs of a production process or activity, including the energy inputs associated with that process.

In addition to the SETAC framework, we relied on two research projects in life-cycle assessment. The first is the Tellus Institute Packaging Study⁹, a life-cycle assessment of packaging materials. In developing the framework for that study, previous LCIs were reviewed and served as a foundation for a modified LCI. The second research project is the US EPA Life-cycle Assessment Research Project. The goal of that project is to develop a comprehensive methodology for performing LCAs. Tellus is participating in the peer review group that is overseeing Battelle's efforts in this project. We have drawn from this work in developing the framework for this report.

An important modification of the LCA/LCI methodology developed for this study is omission of energy value of raw materials inputs that alternatively may be used as an energy source; e.g. wood for paper production and petroleum products for plastics production. Frequently these values appear in the total production energy for a process to emphasize that such material has competing uses as either a production input or an energy resource. This, of course, is true for both virgin and recycled materials. The goal of this project is to determine production energy requirements for virgin and secondary systems, and the inherent energy content of raw materials is extraneous. Thus, this step was eliminated since the energy value of material

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⁸ Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education, Inc. A Technical Framework for LifeCycle Assessments. Washington, DC, January 1991.

⁹ Tellus Institute. Council of State Governments/Tellus Packaging Study. Boston, MA, May 1992.

inputs does not effect the process energy required to manufacture a particular product.

The following sections define the general production system, describe how boundaries are placed around this system, and describe the methodology for quantifying system-wide energy impacts. The framework is generic; i.e., it can be applied to all processes used in the manufacture of products included in this study.

The Production System

The production system comprises three main operations (Figure 3-1). The arrows in the figure represent flows of energy and materials.

- Main production sequence, consisting of the main unit operations
- Ancillary materials (additives) production
- Energy production.

Consider first **virgin materials manufacturing**, which involves three stages in the main production sequence:

- Raw materials acquisition
- Transportation
- Product manufacturing.

Raw materials acquisition includes the activities required to obtain and process raw materials. This stage includes harvesting and cultivating activities required for wood products, and extraction activities such as those required for mining minerals. This stage also includes raw materials processing. Raw materials may be processed further at a manufacturing site to meet input requirements. Such processing is not included in this stage but is part of the third stage -- **product manufacturing**.

Transportation is the movement of materials or energy between operations at *different* locations. For example, movement of raw materials from where they are mined to a production facility is classified as transportation. Movement of materials within a production facility is excluded from our framework, as is transport of fuel to the production facility.

Product manufacturing includes all the activities required to physically transform raw materials into a product. These processes may occur at one site or facility, or at multiple sites and facilities, in the same or different countries. For example, production of intermediate products such as alumina, an intermediate in the production of aluminum, occurs both in and outside of the United States. The alumina is then transported to the United States (an impact quantified in the second stage) for the final stage, aluminum production.

Figure 3-1. Components of Generic Production System.

To illustrate, the production system for virgin aluminum ingots is shown in Figure 3-2. The main production sequence embodies the major operations needed to produce the product. This includes mining of bauxite (an aluminum-bearing ore), transportation of bauxite, transportation of ancillary materials, and several manufacturing stages required for aluminum ingot production. The production of ancillary materials includes mining and processing of lime and production of caustic soda, cryolite, aluminum fluoride, and fluorspar. Energy for aluminum manufacture includes the production of electricity and other fuel sources needed both for the main production sequence and for the production of additives.

In the case of steel and glass manufacturing, some post-consumer recycled material is always mixed with virgin raw materials. In these cases, the virgin systems are modeled using industry averages for post-consumer recycled material content. Home or prompt scrap, however, has not been included in any of the analyses. Instead, the raw materials required to produce this amount of scrap are included since our focus is on the marginal impact of one more tons of cans or bottles. In some cases, more than one technology may be used to produce a product. In this study, we sought to model the dominant production processes used to make the grade of intermediate or final product. Consultation with various industry sources helped us define such dominant processes.

For **secondary materials recycling and remanufacturing**, the main production sequence also includes three stages:

- raw materials acquisition
- transportation
- product manufacturing.

Raw materials acquisition in this context is the procurement of recyclable materials from the waste stream. This includes the collection and processing of recyclables and the transport of recycling residue. Raw materials acquisition also includes any of the initial processing steps that may take place at facilities such as a MRF. The second stage, **transportation**, is the movement of these raw materials from the collection/processing centers of the solid waste system, i.e., the MRF, to the product manufacturing facility. The **product manufacturing** stage includes the processes needed to manufacture a product from these secondary materials. Again, to illustrate using the aluminum industry, these processes for recycled aluminum ingot production are shown in Figure 3-3.

System Boundaries

After defining the production system, the next step is to define system boundaries to delineate which energy impacts will be included and excluded in the analysis. The chain of impacts associated with a production system may be traced far upstream and far downstream in the product life-cycle. As depicted in Figure 3-4, we assume processes inside the box are part of the production system and processes outside the

box are excluded from the system. For this framework, we have set two basic boundary conditions:

One Step Back. We have applied a one-step-back rule: energy inputs were counted for processes one step back from the main production chain, but not for processes two steps back. Thus, the energy inputs associated with mining of raw materials for the main production sequence are included, whereas the energy inputs associated with the production of mining equipment or explosives are not.

Most manufacturing processes require the use of additives in addition to the major raw material. In applying this rule to additives, we considered the energy inputs associated with production of the additives, but not those associated with additives needed for the manufacture of a direct additive. For example, chlorine (an additive in paper production) production requires sulfuric acid as an additive. By our one-step-back rule, the energy inputs associated with sulfuric acid production were not included when assessing the energy requirements for chlorine production.

In applying the one-step-back rule to electricity production, we considered the energy required to make energy; i.e., the Btu value of the fuel input versus the Btu value of the energy output. Note, however, that because the principal purpose of this study is to inform state energy planners, the one-step-back rule is not applied for fossil fuel production. Fossil fuels used in production have been converted to Btus using the at the nozzle value of the fuel and do not include extraction, transfer, processing, or any other precombustion energy.

Greater Than 2.5% of Material Inputs. Additives are included in the production system if the additive comprises more than 2.5% of the total material input required to manufacture a final/intermediate product. We used 2.5% as a cut-off since certain products, for example plastics, require many additives that are used only in very small quantities. We assume such additives do not have a significant effect on the total amount of energy required to manufacture a product.

Appendix III-A contains two manufacturing flow diagrams -- virgin and recycled production -- for each product listed in Table 3-2. These diagrams illustrate the process-specific boundaries developed in accordance with the above rules. Arrows represent material flows. Processes are represented by rectangles. Additives (i.e., material inputs that are not part of the primary production sequence) appear without rectangles. We indicate points of transportation energy use on each diagram.

Figure 3-2 Virgin Aluminum Production System.

Figure 3-3. Recycled Aluminum Production System .

Figure 3-4 Production System Boundaries.

Since recycled aggregate road base is road-ready after processing at the construction and demolition waste recycling facility, the production of this recycled product is included in the solid waste management system rather than manufacturing systems.

Energy Use in the Bounded Production System

We now turn to a discussion of the methodology used to develop and compare energy requirements for virgin and recycled systems.

Reporting of Energy Data. Energy impacts for each stage of production and transport are reported both in the appropriate units of the energy input (e.g., kWh of electricity, pounds of steam) per unit of output for each process or end product. We differentiate among several forms of energy: purchased electricity, electricity generated on site, steam, and energy used for other purposes such as direct heat. These energy values are converted to Btus to permit the calculation of the difference in energy for the virgin and recycling/remanufacturing processes. Units of fuel were converted to Btus by multiplying the quantity of the fuel by the Btu content of the fuel. To convert electricity and steam inputs to Btus, we used conversion factors that account for the Btu value of the fuel used to produce steam and electricity and the energy conversion efficiency of the electricity and steam generation systems (e.g., Btus of fuel/kWh electricity produced) for a U.S. composite electric power plant.¹⁰ Table 3-3 presents the conversion factors used to convert fuels, steam, and purchased electricity to Btus.

For on-site electricity generation, we determined the mix of fuel and conversion efficiencies appropriate to the industrial process. This information is documented in the notes to the Material and Energy Tables.

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¹⁰ A mix of fuels and energy conversion technologies representative of the U.S. average.

TABLE 3-3. BTU CONVERSION FACTORS [1].

<u>Energy Sources:</u>	<u>Unit</u>	<u>Btu/Unit</u>
Oil (Residual)	gallons	149,700
Diesel fuel	gallons	138,700
Gasoline	gallons	125,000
Natural gas	cubic feet	1,031
Coal	net ton	25,000,000
Electricity	kWh	10,500
Steam (at 100 psi from coal-fired boiler)	pounds	1,400

Notes:

[1] Conversion factors for fossil fuels are at-the-nozzle value of the fuel and do not include the energy necessary for extraction, processing, or precombustion.

Sources:

Battelle Columbus Laboratory.
Oak Ridge National Laboratory.
Tellus Institute.

Product Manufacturing Energy Use. Only direct process energy is included in our analysis. Energy that is not integral to production (e.g., space heating) is excluded. In some virgin manufacturing systems, manufacturing residues and/or byproducts are used as process fuels and are included in our analysis. For example, in kraft pulp production (a step in virgin paper products manufacturing, Table III-A.1) wood wastes are recovered and used to fuel steam boilers. In ethylene production (Table III-A.22), much of the process energy results from burning byproducts generated in the production process. The manufacturing material and energy tables in Appendix III-A indicate the breakdown between purchased and residue/byproduct energy sources when wastes are utilized in a manufacturing process (the structure of the energy tables are described below). In some production processes, such as particular steps in plastics manufacture, byproducts are used as fuel energy for other production processes. Production wastes used as fuel elsewhere in the manufacturing facility (i.e. for processes other than those being modelled) are not directly credited, but are noted in the energy tables.

Indirect impacts associated with manufacturing processes include the energy required to operate pollution control devices and the energy required to dispose of waste materials such as sludges and mine tailings. In general, however, there is a paucity of data on industrial solid waste generation rates and the energy consumed to manage these wastes. Thus, we have chosen to omit these data from all analyses.

Frequently, more than one useful, saleable product is produced in a single manufacturing operation. In these cases, total energy inputs were allocated to the various outputs, according to the weight distribution of product outputs. For example, in Table III-A.10, the production of chlorine by electrolysis of brine solution also produces caustic soda and hydrogen gas, two useful co-products. Therefore, allocating all the energy inputs required for brine electrolysis only to chlorine would imply that no energy is required to produce caustic soda and hydrogen. Instead, we allocated the total energy inputs based on the weight of material outputs. To illustrate, during the production of 1 ton of chlorine, 1.2 tons of caustic soda, and 0.03 tons of hydrogen are produced -- a total output of 2.23 tons of products and co-products. Thus, 45% of the total energy for brine electrolysis is attributed to chlorine, 54% to caustic soda, and 1% to hydrogen.

Structure of Material and Energy Tables. The results of our analysis of product manufacturing energy use are reported in Material and Energy tables in Appendix III-A.

There are two types of Material and Energy tables in Appendix III-A. The first type contains material and energy input data for an individual process or grouping of processes that are necessary for the production of a final or intermediate product. For example, Table III-A.40 contains data for bauxite mining and processing, a grouping of processes or unit operations necessary for molten aluminum production. Material and energy data are based on the production of one ton of output for the

process or group of processes. Using the example above, the material and energy data in Table III-A.40 are: units of energy per 1 ton of processed bauxite.

If data for several processes are presented in one table, the energy data for all processes are summed at the bottom of table. In addition, the breakdown of purchased versus residue/byproduct energy sources are presented at the bottom of the tables.

The second type of summary table contains *all* material and energy data for all processes necessary to produce final or intermediate products (incorporating the 2.5% rule discussed above). These tables are denoted by the title Total Material and Energy Inputs:.... Material and energy data are based on the production of 1 ton of final or intermediate product. For example, Table III-A.44, titled Total Material and Energy Inputs: Virgin Molten Aluminum Production, contains material and energy data for all processes needed to produce 1 ton of virgin molten aluminum.

The summary tables draw from the single or multiple process tables described above. Specifically, the summary tables take the energy output for each process (or grouping of processes) and scale it up or down according to quantity of process output needed for the total production system. For example, in Table III-A.44, 8970 pounds of bauxite are needed for the production of 1 ton of molten aluminum. Thus, we take the energy data from Table III-A.40 (Bauxite Mining and Processing) and scale it up by a factor of 8970/2000, since the figures in Table III-A.40 are based on the production of 2000 pounds (1 ton) of bauxite.

The energy data for each process in the summary table is summed, by energy type, and reported at the bottom of the table.

Detailed Description of Virgin and Recycled Manufacturing Systems.

Linerboard. The virgin linerboard manufacturing system begins with wood harvesting, includes kraft pulping, and ends with linerboard production (Figures III-A.1 - Kraft Pulping (includes wood harvesting) and III-A.2 - Virgin Linerboard Production); the recycled system begins with wastepaper pulping and ends with linerboard production (Figure III-A.3). Transportation energy is included in the virgin system for the transport of wood to the mill. Our model is based on an integrated virgin mill (i.e., both pulping and boardmaking occur at one facility), so we do not account for energy used to transport pulp from a pulp mill to a paper mill. Since most virgin integrated linerboard mills are located close to their source of wood raw material, we assume that wood is transported by truck an average distance of 100 miles from the forest to the mill (Table III-B.1).

Newsprint. For both virgin and recycled newsprint production, we estimate energy impacts associated with all steps up to and including

the point of newsprint manufacture. The virgin system is based on a furnish recipe of 95% thermomechanical pulp (Figure III-A.5, Table III-A.6) and 5% semi-bleached kraft pulp, the common practice in modern newsprint mills today.¹¹ The bleaching process, C/DEoD¹², is depicted in Figure III-A.4, and material and energy data for this process are given in Table III-A.5. Total virgin system energy impacts are reported in Table III-A.8. Again, we have modelled an integrated mill, and account for transportation energy only for transport of wood raw materials to the mill.

The recycled system, Table III-A.9, includes waste newsprint pulping with sodium hydroxide, de-inking, cleaning, screening, washing, thickening, and sheet forming and drying.

Printing and Writing Paper. Energy requirements for virgin printing and writing paper production are estimated for roundwood harvesting, kraft pulping, kraft pulp bleaching, to paper forming and drying (Figure III-A.7); and for recycled printing and writing paper production are estimated for wastepaper pulping, and de-inking through forming and drying (Figure III-A.8). Since chlorine and caustic production use for kraft pulping in this system exceed the 2.5% rule for inclusion in the production model, we have included the energy used to produce these materials in our energy analysis (Table III-A.10). Total energy impacts are reported for virgin manufacturing in Table III-A.12, and for recycled manufacturing in Table III-A.13.

Coated Folding Boxboard. Energy requirements for virgin coated folding boxboard production are estimated for roundwood harvesting, kraft pulping, paper forming and drying, and coating (Figure III-A.9); and for recycled folded boxboard production are estimated for wastepaper pulping, through forming and drying and coating (Figure III-A.10). Total energy impacts are reported for virgin manufacturing in Table III-A.15, and for recycled manufacturing in Table III-A.16.

Plastics - HDPE Pellets, LDPE Pellets, and PET Pellets. Energy requirements for virgin plastics production encompass oil and natural gas extraction through the polymerization of each resin into pellets, (HDPE pellets, LDPE pellets and PET pellets). Energy requirements for subsequent processing steps -- molding and forming -- are the same for resins made from virgin and recycled materials. The analysis stops at this point because both virgin and recycled HDPE, LDPE, and PET

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¹¹ Written communication with R.T. Campbell, International Paper, Aug. 1991.

¹² According to R.T. Campbell, International Paper, this sequence is common for the bleaching of kraft pulp.

pellets can be used for some, though admittedly not all, of the same end-uses. LDPE grocery bags, HDPE soda bottle base cups, and PET carpet fiber may be made from either virgin or recycled LDPE, HDPE, and PET, respectively. Closed- and open-loop plastics recycling issues are discussed in more detail below.

All three virgin resins are formed from the polymerization of ethylene, illustrated in Figure III-A.12. Therefore, the material and energy tables for HDPE, LDPE and PET are based on Table III-A.23, Total Material and Energy Inputs: Ethylene Production. In accounting for energy impacts of ethylene, oil and natural gas are assumed to come from onshore wells. The coproducts resulting from the production of naphtha and gas oil (via crude oil processing) have been credited as coproducts on a weight basis, according to the methodology described above. The mix of feedstocks modeled for ethylene production are: 33.6% ethane, 13.1% propane, 26.9% naphtha, and 26.4% gas oil.¹³ As in the production of naphtha and gas oil, the process energy used for ethylene production is allocated to the coproducts produced in this process. HDPE polymerization energy was calculated using the low pressure, gas phase UNIPOL polymerization process,¹⁴ and LDPE using a high pressure polymerization process.¹⁵ Although PET is produced from both terephthalic acid (PTA) and dimethyl terephthalate (DMT), the energy analysis of PET production assumes that all PET is produced from DMT. We make this simplifying assumption owing to the unavailability of energy data for PET production from PTA.

The transportation analysis for virgin plastics production, Table III-B.5, is based on the location of *all* virgin resin producers, not specific types of resin producers, and the transportation energy for raw materials used in the production of all three resins comes from this table. In the transportation analysis, we assume, based on 1989 petroleum demand statistics, that 56% of crude oil for plastics production comes from domestic sources and 44% is imported.¹⁶ Total material and energy impacts are reported for virgin HDPE, LDPE and PET manufacturing in Tables III-A.25, III-A.28 and III-A.33, respectively.

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¹³ Henri Ulrich. Raw Materials for Industrial Polymers, Oxford University Press: New York, NY, 1988. 59.

¹⁴ Hydrocarbon Processing. 1989 Petrochemical Handbook, November 1989.

¹⁵ Gaines and Shen. Energy and Materials Flows in the Production of Olefins and Their Derivatives, 1980.

¹⁶ DeGloyer and MacNaughton. 20th Century Petroleum Statistics, 1990.

Plastics recycling is a rapidly changing industry. The earliest plastics recycling practices usually involved simply regrinding the waste plastic, which turned out waste resin material that was inferior to the virgin version. Closed-loop recycling, manufacturing the material into the same product, was not possible so the recycled plastic would find its way into products such as plastic park benches and flower pots. Historically quality and cost concerns have limited the markets for post-consumer plastic resin, but new technologies and consumer demand for recycled products have encouraged the development of processes that produce quality recycled resins.

For the most part, however, certain types of plastic products, such as those that come into contact with food, do not use post-consumer resins because of liability and/or regulatory concerns. Concerns stem from the fact that plastic containers such as milk jugs are often reused in the home to hold household hazardous chemicals, and that these materials might pose a health hazard if recycled into another food container. New molding and forming technologies, like ones that sandwich a layer of recycled plastic between virgin layers, are being developed so that recycled resins can be used in food applications. Also, several recycling processes that chemically reduce polymers into their building blocks have been approved by the U.S. Food and Drug Administration for use in food applications.

Because virgin resins can be replaced by recycled resins in many applications, and as a necessary simplifying assumption, we assume closed-loop recycling of plastics. It is true that large amounts of recycled resins are used in production of materials that traditionally may not have been made from plastic; e.g., plastic lumber, flower pots, trash cans, and toys. Although many products made from recycled resins are not identical to the product from which the resin was derived, closed-loop recycling efforts have increased tremendously over the past few years. While not precisely closed-loop recycling, many recycled resins are used in place of virgin resins for products other than those from which the resin was derived.

The largest market for recycled PET has been for the production of polyester fibers, or fiberfill, used in products such as jackets, sleeping bags, and furniture. PET is also recycled into carpet, textiles and film. A significant additional market for PET is for consumer bottles used in both food and non-food applications (depending on the recycling method employed). HDPE bottle-to-bottle recycling is well established, and post-consumer resin is used for laundry detergent and other household chemical bottles, automotive product bottles, and base cups for PET bottles. LDPE and HDPE films used in grocery sack production are being recycled back into sacks. Reprocessing firms and

bag manufacturers say they hope to apply the experience they gain in handling and processing comparatively homogeneous wastes like grocery sacs to larger and more diverse post-consumer streams of plastic film from curbside programs and materials recovery facilities.¹⁷

There are three distinct categories of plastics recycling: primary, secondary, and tertiary recycling processes.¹⁸ The process of simply regrinding plastic waste is referred to as primary recycling. As mentioned above, primary recycling results in resins inferior to virgin resins and with very limited end-markets. Secondary recycling involves the physical or thermal reprocessing of waste resin material; the energy analysis in this report is based on information for secondary recycling processes. Secondary recycling produces a resin that can rival virgin resins in quality and may be used in many of the same application; it is the process modeled in this study. Tertiary recycling, also known as chemical reclamation, involves breaking down plastics polymers into their constituent parts, providing an alternative to virgin feedstocks. Chemical reclamation is explored more fully below.

Energy consumption for specific plastics recycling processes is difficult, if not impossible to obtain; only two of the many plastics recyclers we contacted were willing to provide any energy data. A recent report providing an overview of plastics waste management options shared this experience:

Few reliable production or market statistics exist for either scrap or post-consumer plastics. This lack of information reflects the reluctance of resin manufacturers and plastic processors to reveal information which demonstrates the market advantages of recycling and reprocessors who are concerned about releasing information which may be advantageous to their competitors.¹⁹

One plastics recycler provided a range of 500 to 1500 kWh/ton for processing HDPE, LDPE, and PET plastics from baled form to

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¹⁷ California Integrated Waste Management Board. Plastics: Waste Management Alternatives; Use, Recyclability, and Disposal, May 1992, Chapter 5.

¹⁸ *ibid*, Ch 5.

¹⁹ *ibid*, page 12.

extruded pellets (including hot water heating).²⁰ In the energy analysis, the average value, 1000 kWh was used for HDPE and PET processing, whereas we assume that LDPE processing utilizes 1500 kWh due to the higher level of cleaning and processing that these plastics require. The energy necessary for the transportation of used plastics to post consumer processors is based on the number of processors of each resin (Table III-B.10). Total material and energy impacts are reported for recycled HDPE, LDPE, and PET manufacturing in Tables III-A.26, III-A.29, and III-A.34, respectively.

Energy data also was available for Eastman Chemical's chemical recycling process for PET waste. Chemical recycling involves the breakdown of polymeric waste for reuse as polymers, monomers, fuels, or other chemicals. A typical chemical recycling process takes a polymer stream, adds solvent, and uses the resulting chemical product as an alternative feedstock to crude oil. Processes for depolymerization of condensation type polymers (specifically polyesters, polyamides, and polyurethanes) by hydrolysis and glycolysis were patented in the 1960s and 70s. With appropriate temperatures, pressures, and reactive agents, these polymers break and depolymerize in controllable ways.²¹ Complete depolymerization yields a monomer that can be purified by conventional means. Repolymerization of this monomer feedstock yields virgin grade polymer. Resins depolymerized to monomer, purified and then repolymerized are acceptable for food-contact since the endproduct is the same as virgin polymer, a distinct advantage over secondary recycling. Chemical recycling processes have not proved economical in general, nevertheless, they are being pursued at an increasing pace. PET has been the target of most depolymerization research and commercialization.

Three companies have dominated the development of the chemical recycling process of PET waste: Eastman Kodak, Freeman Chemical, and the Polyester Division of Goodyear Tire and Company. Several corporations (Kraft, Pepsi, and Coca-Cola) have received permission from the Food and Drug Administration to use repolymerized in bottles that come into contact with food. In late 1991, Coca-Cola began limited bottling of their products in bottles with 25% post-consumer PET. One method of chemical reclamation is glycolysis. Here a mixture of reclaimed PET, diethylene glycol and manganese is heated to depolymerize the resin. Maleic acid is added to the final

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²⁰ Personal communication with Bruce Bond, WTE Corporation, January 1992.

²¹ M.M. Nir, et al. Update on Plastics and the Environment: Progress and Trends, Technion, Israel Institute of Technology, Haifa, Israel, December 1992. 28.

product to obtain the new PET resin. The recycling method utilized by Eastman Chemical is a methanolysis reaction. In this process, a catalyst and methanol are added to clean PET scrap. The mixture is heated under pressure, which forces the PET to depolymerized into its original components. These materials are purified by recrystallization and distillation, and can be repolymerized for the production of new PET resin.²² Eastman chemical reports that the process energy required to depolymerize PET flake and repolymerize it into PET pellets is 19,100 Btu/lb of pellets, or 38.2 MMBtu/ton. While this number is slightly higher than the process energy required for virgin PET production reported in this report (process energy for PET pellets calculated in Table III-A.33 is 37.36 MMBtu/ton), this is slightly lower than the process energy that Eastman Chemical reports for the production of PET pellets from virgin materials, 21,500 Btu/lb (43.0 MMBtu/ton).²³ While there is a definite energy savings associated with the methanolysis process, it is still a very energy intensive operation, particularly when compared to the secondary recycling process energy requirement of approximately 10.5 MMBtu/ton.

Molten Glass. We have modeled molten glass production, as illustrated in Figures III-A.20 and III-A.21, for two reasons. First, glass is made from a mixture of virgin raw materials and recycled cullet (crushed glass). Recycled cullet requires less energy for melting than does virgin raw materials. However, after melting, the cullet content does not affect the amount of energy consumed by subsequent steps in glass container production: fining and conditioning, forming, and annealing. Therefore, the point of energy convergence in this system is at the point of molten glass production.

Second, because there is no intermediate product between melting and glass container production, container production occurs at the glass factory regardless of the cullet content of the batch mix. Therefore, there are no transportation links between molten glass and glass container forming.

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²² California Integrated Waste Management Board, pages 40-41.

²³ Personal communication with Dave Cornell, Eastman Chemicals, July 21, 1993.

The virgin molten glass system modelled includes 25% cullet content, the average amount of post-consumer cullet commonly utilized.²⁴ Post-consumer cullet has been included in the virgin production system because it is mixed with other raw material prior to the melting process, upstream of the convergence point of virgin and recycled glass production. Although virgin glass producers also use between 5 and 10% process cullet (cullet generated at the plant from breakage), the remaining 75% of the system has been modeled using virgin raw materials. The recycled system modelled uses cullet as the only raw material. Although this is not common industry practice, according to two industry sources the amount of cullet used in glass production is limited by the supply of high quality cullet and not by a technical limit on the amount of cullet that can be used in glass container production.²⁵

Furnace ready cullet requires no further processing at the glass factory prior to mixing with other raw materials. If cullet is delivered unprocessed, it is beneficiated into furnace ready cullet, requiring some additional electricity use. In our energy analyses, we assume that cullet used in both the virgin and recycled systems comes directly from a materials recycling facility and is not furnace ready. Total energy impacts are reported for virgin manufacturing in Table III-A.38, and from recycled manufacturing in Table III-A.39.

Molten Aluminum. For steps subsequent to molten aluminum production in both virgin and recycled aluminum systems -- ingot forming, sheet rolling, and final product forming -- energy use is the same.

In some cases, ingots and sheet are produced at the same facility, and in others ingots are transported from the primary smelter to the rolling facility. In a vertically integrated company, the distance from the smelting facility to the rolling mill is likely to be extremely short. If ingots are purchased on the open market, they can come from numerous locations within the U.S. Typically, however, the rolling facility is within close proximity of the primary smelter for virgin aluminum plants and aluminum processors for recycled aluminum ingot production. Given the two conditions described above, we have chosen to end our production process models at the point of molten aluminum production.

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²⁴ Personal communication with John LeBlanc, Owens-Brockway, May 1992.

²⁵ Personal communication with William Kerns, Central New York Bottle, Miller Brewing Company, Auburn, NY, Sept., 1991 and William Anton, Owens-Illinois Glass Container, Fulton, NY, Sept. 1991.

Aluminum sheet is typically produced from a mix of virgin and recycled aluminum ingots. Virgin and recycled materials may be mixed immediately before ingot production, at the primary smelting facility, or at the rolling mill where virgin and recycled ingots are remelted and rolled into sheet. In either case, virgin and recycled materials are combined after primary molten metal production. Thus, aluminum scrap is not considered an input in the virgin system.

The only alloy comprising more than 2.5% of aluminum can body or lid stock is magnesium. Magnesium accounts for 4.0 to 5.0% of end can stock material input, but only 0.8 to 1.3% of body stock.²⁶ Because the ratio of body stock to lid stock is approximately 3:1, the maximum magnesium concentration in an aluminum can is only 2.23% (calculated using the high end ranges of 5.0% and 1.3%), which falls short of the 2.5% minimum established for inclusion in our analyses. Therefore, alloys are not included in the materials and energy analysis.

As noted in Table III-A.43, energy consumption in the Hall-Heroult process includes energy to manufacture electrolytes and cathodes. Because anodes and most electrolytes are produced on site (often from raw materials already available there), transportation associated with electrolyte acquisition and anode production is negligible and is not included in the transportation analysis. Cathodes however, are made off site, and are included in the transportation analysis.²⁷ Total material and energy impacts are reported for virgin aluminum manufacturing in Table III-A.44, and for recycled aluminum manufacturing in Table III-A.45.

Molten Steel. In the U.S., steel made from virgin iron ore is produced in a basic oxygen furnace (BOF). This process requires approximately 20 to 30% scrap input for proper operation. The addition of scrap to the BOF beyond 30% cannot be done unless additional carbon is added to the mix or unless the scrap is pre-heated. Since this represents additional cost to the mill, it is not done. Typically, steel mills use approximately 10% post-consumer scrap and a 10 - 20% mixture of prompt (steel waste from product fabrication) and home scrap.²⁸

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²⁶ Metals Handbook Desk Edition, American Society for Metals, 1985, pp. 6-25.

²⁷ Using the Alcoa system as a model, where anodes are manufactured at the same site as the aluminum, and cathodes are made externally, imported approximately 750 miles by rail; written communication with Mark Hauser, September, 1991.

²⁸ Personal communication with Gregory Crawford, Steel Can Recycling Institute, September, 1991. Current U.S. industry average in the BOF is 23.5% scrap (written communication with Gregory Crawford, April 1992).

The use of scrap is integral to virgin steel production, normally accounting for 20-30% of input materials. Thus, there is no true virgin system. Using the industry average of 23.5% scrap, we modelled a low scrap case as Molten Steel Production -- BOF (10% post-consumer content), as depicted in Figure III - A.24. The 10% post-consumer content is assigned an energy use based on a recycle steel technology (see below). The remaining 13.5% comprises prompt scrap, the energy requirements of which we assume are equal to its embodied energy; i.e., virgin production equivalent.²⁹ Thus, the energy requirements for a ton of virgin steel molten steel combine a virgin component plus a recycle component to arrive at the low-scrap mix defined above.

Recycled steel production occurs at mini-mills, in electric arc furnaces (EAF), where steel scrap comprises 100% of the furnace charge. We have modeled the EAF system using 100% post-consumer scrap. This process is identified as Molten Steel Production -- EAF (100% Post-Consumer Content) and is illustrated in Figure III-A.25. Note that the waste-to-product ratio for 100% post-consumer steel production is slightly less than one (1986 pounds of scrap steel required to produce 1 ton of EAF produced steel) because secondary steel manufacturing requires a small amount of iron scrap to be added to the process mix.

Although both the BOF and EAF steelmaking processes can use any kind of post-consumer scrap input -- steel/tin cans and ferrous scrap such as white goods -- the final products manufactured at these facilities are different because of the amounts of scrap used. Steel made in the BOF is used primarily for high-end uses such as steel sheet for cans. The EAF produces lower-end products such as steel reinforcing bar because: a) such products can tolerate a higher post-consumer or other scrap content; and b) there is a cost and energy savings associated with remelting steel scrap versus using virgin raw materials.

Once molten steel is produced, there is no difference in energy use for the BOF and EAF (recycled systems) for subsequent processing steps - - billet forming and rebar forming. In addition, for both BOF and EAF operations, molten steel production and forming take place in the same facility, or in separate facilities that are in close proximity. Therefore, there is often no or little energy expended to transport steel from the furnace to the forming operation. Given these two conditions, we have chosen to end our production process models at the point of molten steel production.

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²⁹ An alternative formulation using a recycle energy value for the prompt component of the virgin process would reduce energy use by about 2.54 MMBtu/ton, or approximately 10% of total energy use per ton.

Detinning has not been included as part of scrap processing in either the BOF or EAF energy tables. According to one industry source, the amount of tin in tinplated steel (can) scrap is only about 0.2%, an amount that is unlikely to cause a residual problem in the steel alloy, particularly since steel can scrap only forms a portion of the total scrap charge.³⁰ Total energy impacts are reported for BOF steelmaking in Table III-A.55, and for EAF steelmaking in Table III-A.56.

Aggregate Road Base. Virgin aggregate road base was modelled using unit operations and energy data for industrial gravel production. As illustrated in Figure III-A.26 and Table III-A.57, basic operations include mining, crushing, and washing, resulting in gravel that can be used as road base aggregate.

Lubricating Oil. The production of virgin lubricating oil involves refining crude oil into lubricating oil base stock, the chemical manufacture of additives, and the blending of lube oil base stock and the additives. Rerefining also includes three steps: rerefining of used lubricating oil into lubricating oil base stock, additives manufacture, and blending. Once lubricating oil base stock is produced either from virgin or waste oil, the subsequent steps are the same and require the same quantities of energy.

Some companies manufacturing virgin lubricating oil conduct all three processes mentioned above, but blending and packaging is frequently contracted to businesses who specialize in this area. The case is much the same for rerefined lubricating oil base stock -- it will be sold for subsequent processing into the final lubricating oil product. Based on this information, we do not expect that transportation distances between base stock producers and lubricating oil blenders are measurably different for virgin base stock versus rerefined oil.

Since energy requirements for virgin and recycled systems are the same once the lubricating base oil has been produced, and since we expect no measurable difference in transportation energy impacts beyond this point, our virgin and recycled production process models for lubricating oil ends at base stock production.

As illustrated in Figure III-A.27, virgin lube oil can be produced using two different processes -- solvent extraction or hydrocracking -- following the initial stages of atmospheric and vacuum distillation. We assume that 50% of U.S. virgin lubricating oil base stock production is produced by each process. Actual energy data for the used oil

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³⁰ op. cit., footnote 28.

rerefining process are sparse, but our discussions with rerefiners reveal that the processes in rerefining used oil are very similar to those for refining virgin crude oil (Figure III-A.28).

First, the used oil is heated at atmospheric pressure to remove water. A vacuum is then introduced to distill off the lighter fuel fraction; a stronger vacuum and higher heat strip the lube product from the heavy fuel residue. The lube oil fraction is finished by hydrofinishing. These steps are the same as the atmospheric and vacuum distillation and hydrofinishing steps in virgin lube production, so the process energies of these steps in the virgin system are assumed to be the same for the recycled system and are used in the analysis of the rerefined lubricating base stock oil. Coproducts produced in the rerefining system (the light fuel fraction is sold or used in-house, and the heavy residue sold as asphalt extender), have not been credited.

The quantity of crude oil required for virgin lubricating oil base stock is based upon typical processing yields on paraffinic crude reported in the McKeagan study: 25% for atmospheric and vacuum distillation, 60% for solvent extraction, 50% for hydrocracking, 67% for dewaxing, and 100% for hydrofinishing.³¹ Process energy is credited to useful byproducts produced in each step. The amount of used oil to produce a barrel of rerefined lubricating base stock oil -- 1.59 bbl used oil/bbl rerefined oil³² -- is an average of the input/output ratios for two operating rerefining facilities. Total material and energy impacts are reported for virgin lubricating oil base stock manufacturing in Table III-A.64, and for rerefining in Table III-A.65, which shows 1 barrel of rerefined oil acquired per barrel of lube stock.

Energy Use in Transportation of Raw Materials and Intermediate Products

Virgin Manufacturing Systems. Transportation in virgin manufacturing systems involves a complex network linking raw materials mining, intermediate, and ancillary materials production and the final production process. Some virgin manufacturing systems involve the production of intermediate materials at locations different than those of the final product manufacturing process (in this analysis, final product refers to the last step identified in the energy analysis/convergence point). For example, a large portion of the alumina (an intermediate in the production of aluminum) used by the U.S. aluminum industry is produced outside the United States. The alumina

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³¹ David J. McKeagan and Associates. Market Potential for a Used Oil Rerefinery at CIBRO, Albany, 1991.

³² Personal communication with Mike Ebert, Facility Manager, Safety-Kleen/Breslube, Ontario, and Tom Hillstrom, Facility Manager, Safety-Kleen, East Chicago, IL, January 1992.

is imported and the final stages of aluminum production occur at a U.S. facility. A transportation energy impacts analysis must account for all such links in each manufacturing system.

To calculate the energy impacts associated with materials transport for each production process, the following variables must be quantified: a) the average distance each material travels; b) the common mode of transport for each material (ship, rail, truck, or pipeline); and c) the fuel efficiency for each mode. For each commodity examined there are many and dispersed locations where raw materials are mined and processed, where intermediate and ancillary inputs are produced, and where the main production process takes place.

Each transport link has an origin and a destination. To estimate transport distances for materials used in virgin manufacturing, we used census data and statistical surveys to determine the dominant geographical routes along which each material input flows. The dominant route is defined as the route from the nearest geographical concentration of mining of each raw material or intermediate/ancillary product manufacture -- the origin -- to the dominant locations of the main production process within the United States -- the destination.

Our methodology consists of two steps. First, we identify predominant locations of intermediate and final product processing facilities. To define the dominant transportation routes of materials for each production process, we have identified the regions accounting for approximately 70% of final product production (primary aluminum production, plastics resins production, etc.). We have allowed for a 5% shortfall toward this 70% target, applied at our discretion in instances where accounting for the small difference would add unwarranted complexity to the analysis. (For instance, there is a small amount of virgin aluminum produced in New York State, but this is not a dominant source of virgin aluminum, and modeling the transport from these small facilities greatly complicates the analysis.) Second, we match to these destinations the geographical origins of either raw materials or intermediate products, based on geographic proximity. This methodology assumes that intermediate and final processing plants draw their raw materials/intermediate products from the closest source. This is based on the premise of minimizing shipping costs. To describe our methodology in greater detail, we begin with a discussion of destination selection and then follow with origin selection, travel distance, and energy use.

Destinations. Destinations are locations in the main production sequence where raw materials are refined into intermediates or where final products are manufactured. Thus, destinations are the locations to which raw materials, intermediate products, and ancillary materials are transported. There are two types of destinations to consider: intermediate destinations, which may be within or outside the United States, are the locations where intermediates are produced (for example, where bauxite is refined into alumina); and final destinations,

the locations at which the commodities considered in this analysis are actually produced (where alumina is smelted into aluminum, where molten steel is produced, etc). Final destinations, for the purpose of this study, are always located in the United States.

Intermediate destinations are stops between raw materials acquisition and the final product production process. In this capacity, they serve as both destinations for raw materials *and* as origins of intermediate materials used in subsequent production processes. In Table III-B.7, refineries in Australia are the *destinations* for bauxite mined in that country and the *origin* of alumina used for aluminum production by smelters in the Pacific Northwest. Because intermediate destinations are origins of materials used at the final destination, they are identified in the same manner as origins, which is described below.

For the purposes of this study, we define final destination locations for each commodity as the states or regions where, when aggregated, approximately 70% of total U.S. production of that commodity occurs. Of the different measures of output, tonnage best captures the quantity of materials produced, and is used when such data was available. Other means of measurement are footnoted as such in the tables.

Earlier we noted that the final destination need only account for 70% of U.S. production. In order to make this analysis representative of the entire industry, this 70% must be scaled to 100%. Therefore, the actual percentage of U.S. production accounted for by the locations identified is normalized to 100%, so that the identified locations capture 100% of the industry. To illustrate, in 1989 the Pacific Northwest accounted for 35.3% of U.S. primary aluminum production, the Midwest region for 26.1%, and Texas for 7.7%; this represents 69.1% of U.S. primary aluminum production. After normalization, we attribute 51.0% of primary aluminum production to the Pacific Northwest, 37.8% to the Midwest, and 11.2% to Texas, thereby accounting for 100% of U.S. aluminum production. These percentages are shown in Tables III-B.1 through 9 as normalized % production.

Origins. Origins are the locations where raw materials are extracted, or where intermediate or ancillary materials are manufactured. Materials used by U.S. manufacturers may be acquired domestically, imported, or both. If 70% or more of raw or intermediate materials production occurs in the United States, only domestic suppliers of raw materials are considered. However, if domestic production does not account for at least 70% of U.S., consumption of a material then both imports and domestic supplies must be considered as origins of the material.

After identifying the geographical regions (domestic and/or foreign) that are significant suppliers of the material to U.S. industries, destinations (both intermediate and final) are linked to their known suppliers. For example, Australian refineries are linked to Pacific Northwest smelters. In most cases, however, no specific location of raw or intermediate materials is available. To simplify, we assume that transportation distance is the dominant factor in determining the location from which raw materials and intermediates are obtained and destinations are geographically matched to the nearest concentration of raw or intermediate material production. Thus, in cases where destinations (primary manufacturing locations) are situated near a substantial source of raw material or intermediate or ancillary product, we assume that the material is acquired from this origin and not from the leading producer of that material.

Table III-B.6 illustrates these assumptions. While 72% of the nation's feldspar is mined in North Carolina, we assumed that 100% of the feldspar used by California's glass industry comes from southern California -- the second largest producer of feldspar. In cases where a manufacturing process uses materials that are mined/produced in their own state, as is often the case with limestone and lime, we assume that the raw material origin is a distance of 100 miles from the corresponding destination.

In Tables III-B.1 through 9, the column labelled % Supply for Destination represents the amount of material arriving at a destination from each of its sources. When destinations are matched to only one supplier (origin), we assume that this origin supplies 100% of the material flowing into the production process, and the % Supply for Destination in Tables III-B.1 through 9, equals 100%. For example, Australian refineries receive 100% their bauxite from nearby mines. When a number of origins of a material are identified for a particular destination (as indicated in the literature or when matching leads to origins with similar distances from the production location), we developed assumptions about the % Supply for Destination from each source. For example, imports of bauxite to the Gulf Coast in 1989 included 31.7% from Guinea and 31.2% from Jamaica. We normalized these percentages to account for all the bauxite refined in the Gulf Coast, and assumed that 50.4% of the bauxite came from Guinea and 49.6% from Jamaica.

Estimation of Travel Distance and Energy Use. The percentage of material inputs traveling along each route, the % Traveling This Route was calculated by multiplying the % Supply for Destination by the Normalized % Production at the destination. The distance between each origin and destination is measured in miles. Note that this is an

approximation, as all transportation routes were measured along straight lines between the two points, with the exception of shipping routes where it was necessary to approximate travel distances around land masses. This approximate mileage is multiplied by the "% traveling this route" to obtain the "weighted miles" measurement for each route. The mode of transportation was identified from the literature, or when unavailable, a mode was assumed. Final determination of the "MMBtu/ton" for each raw material is calculated by multiplying the "weighted miles" by the "Btu/ton-mile" for that mode of transportation and dividing by one million. Obviously, because only one Btu/ton-mile is used for each mode of transportation we have made a necessary simplifying assumption that all materials are transported with the same efficiency, i.e. that all materials have similar bulk densities.

Recycled Manufacturing Systems. Capturing the energy impacts of transportation in recycling systems involves the quantification of the similar variables as those outlined for virgin manufacturing: a) the average distance traveled by the recyclable material from the MRF to the manufacturing plant (this is analogous to the transport of virgin raw materials from the mine/forest to the first manufacturing facility); b) the common mode of transport for each material (ship, rail, or truck); and c) the fuel efficiency for each mode. The methodology used to model this system, however, is different from the virgin system methodology described above.

Recyclables are collected at MRFs, redemption centers, and other recycling facilities throughout the nation, thus the origins of recyclable materials for secondary manufacturing systems are numerous and disperse. Because there is no particular geographic concentration of these materials, we do not identify specific origin locations. Instead, we estimate the distance traveled by recyclable materials using data on the number of secondary production or processing facilities in the United States (the facilities where recyclable are transformed into the final or intermediate products; i.e., aluminum cans and foil are converted into molten metal at UBC processing centers and at primary smelters).

We begin with the assumption that the fewer the number of secondary production facilities or processing centers, the further recyclable must travel to reach a manufacturing facility. Conversely, if there are hundreds of facilities, it is likely that most MRFs are within a short distance of at least one facility. Using this premise, we developed guidelines for assigning a travel distance to each recyclable material according to the number of U.S. manufacturing facilities using recycled materials. These guidelines, presented below, were developed by estimating the average distance material must travel from all points in the U.S. given the number of existing manufacturing facilities:

- 5 facilities or less: 750 miles
- 6 to 15 facilities: 500 miles
- 16 to 99 facilities: 250 miles
- 100 or more facilities: 100 miles

Estimation of Travel Distance and Energy Use. As described above, the distance recyclables travel to destinations is estimated from the number of destination facilities. In Table III-B.10 (Appendix B), this approximate mileage is multiplied by the % Mode and Btu/Ton-Mile for each mode, resulting in the MMBtu/ton for the transport of each recycled material. Again, bulk densities for all materials are assumed to be the same. While this may underestimate the energy requirements for transporting recycled plastic, keep in mind that plastics have undergone initial processing at the MRF, and are in baled form. Because transportation energy requirements tend to be small as compared to process energy (see summary Table 3-4) for all virgin and secondary manufacturing processes, this assumption should not skew the results of the study in any fashion.

Results

The results of our analysis of manufacturing systems energy use for 12 final/intermediate products is presented in Table 3-4, and graphically in Figures 3-5 and 3-6. Energy data are reported in MMBtu per ton final or intermediate product for the virgin and recycled system as follows:

- Total Energy
- Process Energy
- Transportation Energy
- Recyclables Acquisition Energy.

The Recyclables Acquisition Energy value used in this table, for all waste materials except wood waste and aggregate, is 0.55 MMBtu/ton. This value is an average value for Scenarios A, B, and C analyzed in NYC GEIS, and consists of energy use for recyclables collection, processing, and transport of recycling residue from the MRF to the landfill. A value of 0.25 MMBtu/ton is an average value for the three Scenarios for materials processed at construction and demolition facilities (C&D).

Shifts in On-Site and Purchased Energy Sources. In some virgin production systems, a substantial amount of the energy required for particular processes is generated on-site by using process residues as fuel or by generating electricity at the facility. A shift from virgin to recycled production of a material in a particular region could increase energy demands in that region, a fact which should not be overlooked by energy planners. While paper, plastic, aluminum, and steel all rely, to varying degrees, on-site energy generation technologies, a shift from virgin to recycled paper

production in a region would have the greatest impact on energy needs in that region. Recycled paper production of all four materials examined in this study requires less total energy per ton than virgin production; however, for all but newsprint production, which requires a large amount of purchased energy relative to on-site energy in virgin production, the recycled production process requires more **purchased** energy than the analogous virgin system. In virgin paper production systems residues and process wastes such as bark and fines from both kraft and thermomechanical pulp production are used as an energy source in subsequent processing steps. Energy generation from this residue/by-product combustion accounts for anywhere from 11 to 70% of the total energy needs in virgin linerboard, newsprint, printing and writing paper, and boxboard production. Recycled production, however, is entirely dependent on purchased energy sources. Table 3-5 summarizes the total and on-site energy requirements for these paper production processes, and allows for comparison to purchased energy needs in the corresponding recycled production system.

More detailed breakdowns of energy requirements for paper production can be found in Tables III-A.1 through III-A.16 of Appendix III-A. Table 3-5 clearly illustrates that secondary production of linerboard, printing and writing paper, and boxboard requires more purchased energy than that for virgin processes, although recycled newsprint requires less purchased energy. Thus, a shift to secondary paper production in a region could, while requiring less total energy than virgin production, increase energy generating demand in the region.³³

On-site energy sources are also used in virgin aluminum, plastics, and steel production, but on-site energy is a small fraction of total energy use. On-site electricity generation accounts for 14% of the total energy required in the production of a ton of molten aluminum (21.55 MMBtu, see Table III-A.44). Secondary aluminum production requires 9.01 MMBtu/ton, all of which is purchased (Table III-A.45, including acquisition energy), but this is far less than the purchased energy required for virgin aluminum production (130.55 MMBtu/ton, includes transportation energy).

During the production of ethylene, byproducts are burned as fuel, and accounts for 83% of the energy consumed in ethylene production step of plastics manufacturing (Table III-A.22). This is not the **total** energy required in ethylene production, but only the step where ethylene is produced from feedstocks; it does not include raw materials mining and processing. By the time ethylene is polymerized into HDPE, LDPE, or PET, ethylene process energy accounts for less than 30% of the total process energy. And again, because virgin plastics production requires far more

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³³ Materials where coproducts are a result of the manufacturing process could not be included in Table 3-5 because the energy breakdowns were not consistent with table categories. For energy information for additional materials please see Appendix III.

energy than the recycled process, more purchased energy is required by the virgin than the secondary process.

Both blast furnace and coke oven gases, as well as tar and pitch, are recycled as energy sources in basic oxygen furnace production of steel. Coke oven gas is recycled as fuel during coke production (Table III-A.51) and tar, pitch, and both gases are used as fuel during pig iron production (Table III-A.53). Per ton of molten steel produced (10% post-consumer content) these by-products account for 19.5%, or 4.72 MMBtu/ton, of the production energy requirements; (for detailed breakdown see Table III-A.55). Purchased energy requirements are 19.50 MMBtu/ton. The purchased energy requirement for the electric arc furnace, 100% post-consumer content, is 5.04 MMBtu/ton molten steel (Table III-A.56, not including acquisition energy listed in Table 3.4). Again this is far less than the purchased energy required for the "virgin" production system.

TABLE 3-4. SUMMARY OF MANUFACTURING SYSTEMS AND WOOD WASTE COMBUSTION ENERGY DATA
(MMBtu per ton intermediate or final product).

FINAL/INTERMEDIATE PRODUCT[6]	VIRGIN PRODUCTION	RECYCLED PRODUCTION	VIRGIN - RECYCLED	TONS WASTE/ [7] TON PRODUCT	ENERGY COEFFICIENT
Linerboard					
Total Energy	25.19	22.54	2.65	1.15	2.30
Production Process Energy	24.28	20.74			
Production Transportation Energy	0.91	1.44			
Recyclables Acquisition Energy [1]		0.36			
Newsprint					
Total Energy	28.30	17.64	10.66	1.17	9.11
Production Process Energy	27.81	15.55			
Production Transportation Energy	0.49	1.73			
Recyclables Acquisition Energy [1]		0.36			
Printing/Writing Paper					
Total Energy	27.64	17.27	10.37	1.14	9.10
Production Process Energy	26.62	16.19			
Production Transportation Energy	1.02	0.72			
Recyclables Acquisition Energy [1]		0.36			
Coated Folding Boxboard					
Total Energy	25.91	23.11	2.80	1.03	2.72
Production Process Energy	25.00	22.10			
Production Transportation Energy	0.91	0.65			
Recyclables Acquisition Energy [1]		0.36			
HDPE Pellets					
Total Energy	51.79	11.49	40.30	1.00	40.30
Production Process Energy	45.05	10.50			
Production Transportation Energy	6.74	0.63			
Recyclables Acquisition Energy [1]		0.36			
LDPE Pellets					
Total Energy	65.66	17.36	48.30	1.00	48.30
Production Process Energy	58.73	15.75			
Production Transportation Energy	6.93	1.25			
Recyclables Acquisition Energy [1]		0.36			
PET Pellets					
Total Energy	44.55	12.11	32.44	1.00	32.44
Production Process Energy	37.36	10.50			
Production Transportation Energy	7.19	1.25			
Recyclables Acquisition Energy [1]		0.36			
Molten Glass					
Total Energy	7.03	5.49	1.54	1.00	1.54
Production Process Energy	6.72	4.50			
Production Transportation Energy	0.31	0.63			
Recyclables Acquisition Energy [1]		0.36			

TABLE 3-4 (CONTINUED). SUMMARY OF MANUFACTURING SYSTEMS AND WOOD WASTE COMBUSTION ENERGY DATA
(MMBtu per ton intermediate or final product).

FINAL/INTERMEDIATE PRODUCT	VIRGIN PRODUCTION	RECYCLED PRODUCTION	(VIRGIN - RECYCLED)	TONS WASTE/ TON PRODUCT	ENERGY COEFFICIENT
Molten Aluminum					
Total Energy	152.05	9.37	142.68	1.11	128.42
Production Process Energy	147.59	8.32			
Production Transportation Energy	4.46	0.69			
Recyclables Acquisition Energy [1]		0.36			
Molten Steel					
Total Energy	24.23	5.40	18.83	0.99 [2]	18.96 [8]
Production Process Energy[9]	23.47	4.42			
Production Transportation Energy	0.76	0.62			
Recyclables Acquisition Energy [1]		0.36			
Aggregate Road Base					
Total Energy	0.05	0.26	-0.21	1.00	-0.21
Production Process Energy					
Production Transportation Energy					
Recyclables Acquisition Energy [3]		0.26			
Lubricating Oil Base Stock (per bbl)					
Total Energy	2.58	0.68	1.90	1.00	1.90
Production Process Energy	2.36	0.42			
Production Transportation Energy	0.22	0.26			
Recyclables Acquisition Energy		n/a			
WOOD WASTE COMBUSTION					
Wood Waste [4]					
Total Energy Value	NA	-12.64	NA	NA	-12.64
Energy Value[5]	NA	-12.90	NA		
Recyclables Acquisition Energy [3]	NA	0.26	NA		

Notes:

- [1] Based on average energy value of 362,000 Btu/ton of recyclables from Scenarios A, B, and C of the New York City Solid Waste Management Planning Project. Includes collection and processing of recyclables, and transport of recycling residues.
- [2] Secondary steel manufacturing requires some scrap iron to be added to the process mix, therefore the amount of scrap steel required is less than 2000 pounds/ton.
- [3] Based on average energy value of 261,000 Btu/ton of construction and demolition waste (C&D) from Scenarios A, B, and C of the New York City Solid Waste Management Planning Project. Includes collection and processing of C&D, and transport of residues.
- [4] Wood waste has no virgin production counterpart. Therefore, the energy coefficient for wood fuel combustion is the sum of the energy generated from its combustion plus the energy consumed in acquisition of the wood from the waste stream.
- [5] Based on average energy value of 8600BTU per pound of oven-dried wood. Neal, Homer A. and Schubel, J.R.. "Solid Waste Management and the Environment: The Mounting Garbage Crisis," Prentice-Hall, Inc., 1987. p.17.
- [6] For each material, recycled and virgin product quality are assumed to be equal.
- [7] Ratio reflects percentage of material lost during recycling manufacturing process as sludge or residue.
- [8] This coefficient would be 16.45 if the industry average use of 13.5% prompt scrap in making "virgin" steel were used in addition to the 10% post consumer scrap use that is assumed in this analysis (see p.3-24).
- [9] Assumes a mix of 10% post-consumer content, which uses recycled steel energy inputs, plus 13.5% prompt scrap, which uses virgin steel energy inputs.

Figure 3-5. Manufacturing Systems Energy Consumption -
Virgin vs. Recycled.

FIGURE 3-6. Manufacturing Systems Energy Consumption - Process, Transportation, and SW System Energy .

Table 3-5. On-site Versus Purchased Energy Requirements Not Including Transportation Energy in Virgin and Secondary Materials Production.
VIRGIN **SECONDARY**

End Product	On-Site Generation (MMBtu/ton)	Purchased Energy Needs (MMBtu/ton)	Total Energy Required (MMBtu/ton)	Total Energy Required (MMBtu/ton)
Linerboard	16.47	7.81	24.28	20.74
Newsprint	2.78	25.04	27.82	15.55
Printing & Writing Paper	18.42	8.20	26.62	16.19
Boxboard	16.47	8.53	25.00	22.10
Aluminum	21.55	126.04	147.59	8.32
Aggregate Road Base	0.00	.05	.05	NA

Comparison to Earlier Work. The unique methodological approach of this study makes comparisons to previously published reports difficult. In March 1982, the U.S. Department of Energy issued a study reviewing published literature (from the 1970's) concerning energy savings that might be realized from manufacturing glass, newsprint, corrugated containers, tissue paper, steel, and aluminum from recycled rather than virgin materials.³⁴ Because the study synthesizes the results of various reports, there is no consistent analytical approach applied for each of the materials, making a comparison to the data reported in Table 3-4 even more difficult. In addition, the DOE study looks at finished products such as glass containers and finished steel as the unit of comparison between virgin and secondary systems, whereas our study examines the energy difference between virgin and secondary manufacturing up to the convergence point of the two systems; i.e., molten glass, molten steel, and molten aluminum. For most of the materials examined, the DOE study includes the energy

³⁴ Marc L. Renard, National Center for Resource Recovery. A Review of Comparative Energy Use in Materials Potentially Recoverable from Municipal Solid Waste, prepared for U.S. Department of Energy, March 1982.

required for mining and transport of virgin materials, but there is rarely an analogous acquisition energy included for the recycled materials (some recycled systems include transport of recyclables).

While the various methodologies and different production system end points make a direct comparison of the energy coefficients calculated here and the Specific Energy Savings from recycled manufacturing reported in the DOE report inappropriate, the studies do indicate the same trends in savings result from the introduction of recyclables into the manufacturing sector. The DOE report determines the following energy savings from secondary production:

Glass containers	4.8	MMBtu/ton
Newsprint	10.0	MMBtu/ton
Corrugated containers	0.0	MMBtu/ton
Tissue/toweling	-1.1	MMBtu/ton
Finished steel	25.2	MMBtu/ton
Aluminum ingot	209.0	MMBtu/ton

The savings reported for glass container production is for increasing cullet content from 15 to 100%, and is primarily a result of decreased energy requirements in the melting process with increased cullet content, and the raw materials energy savings. These are the same two factors which contribute to the energy coefficient reported in Table 3-4.

Perhaps the most interesting comparison between results for the DOE study and this report is in paper production, as both highlight the importance of considering purchased energy in the analysis. The paper savings reported above, taken from the DOE study, are for purchased energy only. As we earlier noted, purchased energy requirements in secondary paper production are often the same as or higher than for virgin production. For this reason, the DOE study reports no energy savings associated with secondary corrugated production, and a negative savings for secondary tissue production. While neither of these materials are examined in this study (corrugated is recycled to linerboard), they show the same trend in purchased energy requirements as illustrated in Table 3.5 for linerboard, printing and writing paper, and boxboard. In both the DOE study and our study, there are purchased energy savings associated with secondary newsprint production (10.0 MMBtu/ton and 7.2 MMBtu/ton, respectively).

The DOE analysis of steel compares the energy requirement for virgin steel production, using national average production mix in open hearth, basic oxygen, and electric arc furnaces to 100% scrap input into electric arc furnace. Thus, while the virgin system includes scrap, the basis for determining energy requirements is very different than ours. Nevertheless, both the DOE and this report demonstrate sometimes significant energy savings from recycled production, 25.2 MMBtu/ton and 18.9 MMBtu/ton respectively. Both the DOE study and this report indicate that largest energy savings as a result of secondary manufacturing is for aluminum

production. The marked decrease is associated primarily with the elimination of the reduction of alumina to aluminum (Hall-Heroult process), the most energy intensive step in virgin aluminum production.

Sources and Limitations of Energy Data

We derived our energy data primarily from three types of sources: 1) DOE funded surveys of industrial process energy use; 2) trade association/industry funded surveys of industrial process energy use; and 3) personal contacts with industry representatives (e.g. International Paper, Steel Can Recycling Institute, Alcoa, Owens-Brockway, and Wte Corporation).

Despite our best efforts to obtain the most up-to-date and representative data for the industrial processes, some data, particularly those from the DOE studies, are potentially outdated. In addition, some data may not be completely representative of the most common industrial practices today. The reader is directed to the footnotes to the tables in Appendix III, which document the sources and any assumptions used in selecting or manipulating the data. This documentation can point the way for future studies designed to improve on this analysis.

Section 4

ENERGY IMPACTS OF WOOD WASTE RECOVERY

In each solid waste management scenario, over 400,000 tons/year of wood waste is diverted from landfills (Table 2-16). Sources of wood waste are varied and include commercial, institutional, industrial, and residential generators. The recovered wood waste inventoried in this report is wood specifically from one of the special waste streams, construction and demolition wastes. We limit the inventory to this component because approximately 76% of wood waste generated in New York City is generated as construction, and demolition debris. End-use markets for recovered wood waste include fuel, various landscaping materials, compost bulking agent, animal bedding, and manufactured building products.¹ Because the New York City GEIS assumes all recovered wood waste is reused as boiler fuel, rather than recycled, wood waste is discussed separately from the recyclables in Section 3.

Characteristics of the wood waste depend upon its source. Construction and demolition debris typically include three different classifications of wood waste: harvested wood, untreated wood, and treated wood.² Harvested wood waste is often called virgin wood. This material includes the stumps, tops, limbs, and whole trees. Besides soil materials, non-wood contaminants are minimal in harvested wood waste. In the construction industry, harvested wood is a result of landclearing for development. The remainder of construction and demolition wood waste is produced from the construction, renovation, and demolition of buildings, roads, piers, and other structures. The wood waste resulting from these activities is varied in both physical and chemical make-up. Untreated wood includes framing and scrap wood. Treated wood may include plywood, pressure or creosote treated wood, and laminates. Because of the heterogeneity of construction and demolition wood waste, it is often difficult to find end-use markets for these materials.

A study entitled Sources and Disposition of New York City Wood Waste³ reported that the types of wood waste generated the City and surrounding areas include

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¹ Christine T. Donovan, "Wood Waste Recovery and Processing," Resource Recycling, March 1991.

² Steve Apotheker, "Construction and Demolition Debris -- the Invisible Waste Stream," Resource Recycling, December 1990. 65.

³ Report to the Recycling Programs and Planning Division, NYC Department of Sanitation, by Atlantis, Inc., August 1990.

construction scrap, demolition debris, crates and pallets, treated wood (such as rail lines, telephone poles, and pilings) and harvested, or green wood from tree trimmings and land clearing. As detailed in Section 2, our modeling anticipates almost 2.5 million tons of construction and demolition debris to be generated in New York City in the year 2000. The wood component of construction and demolition is estimated to be 32% wood. The total wood waste diverted from the waste stream, 406,521 tons/year (Table 2-16), was calculated using anticipated diversion rates of 50% for all categories of wood.

According to the Associated Building Contractors of the Triple Cities, Inc. and the General Building Contractors of New York State, use of processed wood waste as boiler fuel by industrial facilities and wood-fired power plants is listed first of four dominant markets for recycled wood in the Northeast.⁴ Thus, we make the simplifying assumption that all wood waste diverted from the waste stream is used as steam boiler fuel. The wood waste coefficient used to represent the energy impact associated with diversion of this material from the solid waste stream is the energy value of steam generated from the combustion of this material for industrial processes or power production.

To estimate energy recovery from wood waste, we used an average Btu value of wood -- 8600 Btu/lb⁵ -- multiplied by the average energy production efficiency associated with wood fuel boilers -- 75%⁶. This translates into an energy value of 12.90 MMBtu/ton for wood waste. This number excludes the acquisition energy calculated in Section 2, that is, energy required to move the waste material from its point of generation to the processing facility and processing it into chips. As described in Section 2, the wood component of construction and demolition waste is sent to a wood chipper or shredder and processed into wood chips. The acquisition energy for wood waste, 0.26 MMBtu/ton, is based on the average energy value of 261,000 Btu/ton from Scenarios A, B, and C for collection and processing of construction and demolition wastes. In Table 4-1 below, the energy value of the wood waste is reported as a negative number for the recycled production system, which signifies a negative energy use or energy benefit. As in Table 3-4, acquisition energy is an energy use, and therefore a positive number. Thus, the net energy value for recovered wood waste is -12.64 MMBtu/ton.

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⁴ Associated Building Contractors of the Triple Cities and the General Building Contractors of New York State, Managing Construction and Demolition Debris: Trends, Problems and Answers. March 1990.

⁵ Homer A. Neal and J.R. Schubel, Solid Waste Management and the Environment: The Mounting Garbage Crisis. 17.

⁶ Based on a conservative estimate from the BIOPOWER: Biomass and Waste-Fired Power Plant Performance and Cost Model, preliminary version 0.95. Electric Power Research Institute. April 1993.

Table 4-2 presents the total energy benefits from wood waste combustion, -5.14×10^6 MMBtu. This is calculated based on the number of tons of wood waste available for combustion multiplied by the energy coefficient for wood waste combustion from Table 4-1.

If we compare this value to the energy generation of the solid waste system special waste streams, not including wood waste combustion, of -9.88×10^5 MMBtu, wood waste combustion generates more than five times as much energy than is generated through combustion of medical waste and harbor debris, and from landfill gas production from sludge landfilling.

Comparing the energy coefficient for wood waste combustion of -12.64 MMBtu and the energy coefficients of the recyclable manufacturing in Table 3-4, combusting wood waste ton for ton provides more energy generation than the energy savings from recycling linerboard, newsprint, printing/writing paper, coated folding boxboard, molten glass, aggregate road base, or lubricating oil base stock (per bbl). Thus, the importance of wood waste combustion in an overall system energy analysis should not be underestimated.

TABLE 4-1. SUMMARY OF WOOD WASTE ENERGY DATA
(MMBtu per ton).

FINAL/INTERMEDIATE PRODUCT	NET ENERGY GENERATED FROM COMBUSTION
Wood Fuel	
Total Energy Value	-12.64
Energy Value[1]	-12.90
Recyclables Acquisition Energy [2]	0.26

Notes:

[1] Based on average energy value of 8600Btu/lb of oven-dried wood. Neal, Homer A., and Schubel, J.R., "Solid Waste Management and the Environment: The Mounting Garbage Crisis," Prentice-Hall, Inc. 1987. p.17.

[2] Based on average energy value of 261,000 Btu/ton of construction and demolition waste (C&D) from Scenarios A, B, and C of the New York City Solid Waste Management Planning Project. Includes collection and processing of C&D, and transport of residues.

TABLE 4-2. WOOD WASTE COMBUSTION ENERGY IMPACTS.

Material	Tons Diverted/Year	Manufacturing Energy Coefficient (MMBtu/ton)	Total Energy Savings (MMBtu/yr)
Wood Waste	406,521 [1]	-12.64	-5.14E+06

Notes:

[1] From Table 2-14.

Section 5¹

ENERGY IMPACTS OF THE TOTAL SYSTEM:

THE CASE OF NEW YORK CITY

In this section, we combine the results of two components -- the direct effects of the solid waste management system, from Chapter 2, and the indirect effects in the product manufacturing system, from Chapter 3 -- into a total systems analysis. Here the data is presented in two forms, first without allocation to geographic regions (the global perspective) and second with such allocation. The New York City solid waste management planning scenarios illustrate how such total system estimates look for a specific waste stream and management strategy.

GLOBAL ENERGY ANALYSIS

In this section, we add energy impacts associated with recycling of wastes to the energy analysis of New York City's four solid waste management planning scenarios - A, B, C, and D. To do this, we recalculate the energy coefficients in Table 3-4 because these coefficients contain a value for collection, processing, and transport of recyclables (called Recyclables Acquisition Energy which is comparable to raw material extraction and processing for the virgin system) and the energy data for the New York City scenarios already contain that component of energy use. The recalculated energy coefficients are presented in Table 5-1.

Note that the only difference between Table 3-4 and Table 5-1 is the absence of Recyclables Acquisition Energy component in Table 5-1. Coefficients contained in Table 3.4 show the difference between manufacturing a product/intermediate product from virgin raw materials versus recyclables where the following system components are included:

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¹ Appendix V corresponds to this section.

TABLE 5-1. SUMMARY OF MANUFACTURING SYSTEMS ENERGY DATA FOR NEW YORK CITY CASE STUDY

(MMBtu per ton intermediate or final product).

FINAL/INTERMEDIATE PRODUCT	VIRGIN PRODUCTION	RECYCLED PRODUCTION	VIRGIN - RECYCLED	TONS RECYCLABLE: TONS PRODUCT	ENERGY COEFFICIENT
Linerboard					
Total Energy	25.19	22.18	3.01	1.15	2.62
Process Energy	24.28	20.74			
Transportation Energy	0.91	1.44			
Newsprint					
Total Energy	28.30	17.28	11.02	1.17	9.42
Process Energy	27.81	15.55			
Transportation Energy	0.49	1.73			
Printing/Writing Paper					
Total Energy	27.64	16.91	10.73	1.14	9.41
Process Energy	26.62	16.19			
Transportation Energy	1.02	0.72			
Coated Folding Boxboard					
Total Energy	25.91	22.75	3.16	1.03	3.07
Process Energy	25.00	22.10			
Transportation Energy	0.91	0.65			
HDPE Pellets					
Total Energy	51.79	11.13	40.66	1.00	40.66
Process Energy	45.05	10.50			
Transportation Energy	6.74	0.63			
LDPE Pellets					
Total Energy	65.66	17.00	48.66	1.00	48.66
Process Energy	58.73	15.75			
Transportation Energy	6.93	1.25			
PET Pellets					
Total Energy	44.55	11.75	32.80	1.00	32.80
Process Energy	37.36	10.50			
Transportation Energy	7.19	1.25			
Molten Glass					
Total Energy	7.03	5.12	1.91	1.00	1.91
Process Energy	6.72	4.49			
Transportation Energy	0.31	0.63			
Molten Aluminum					
Total Energy	152.05	9.01	143.04	1.11	128.75
Process Energy	147.59	8.32			
Transportation Energy	4.46	0.69			
Molten Steel					
Total Energy	24.23	5.04	19.19	0.99	19.33
Process Energy	23.47	4.42			
Transportation Energy	0.76	0.62			
Aggregate Road Base					
Total Energy	0.05		0.05	1.00	0.05
Process Energy					
Transportation Energy					
Lubricating Oil Base Stock (per bbl)					
Total Energy	2.58	0.67	1.91	1.00	1.91
Process Energy	2.36	0.42			
Transportation Energy	0.22	0.25			

Virgin System Energy Components

Raw material extraction and processing

Product/intermediate production process

Transport of raw/intermediate materials to production process

Recycled System Energy Components

Recyclables collection, processing, and transport of residue from processing facility to disposal facility (recyclables acquisition energy)

Product/intermediate production process

Transport of recyclables/intermediates to production process

Coefficients in Table 5-1 should be used when combining energy impacts from the manufacturing system with energy impacts from a SWM system to avoid double counting of recyclables acquisition energy (i.e., where the SWM system energy analysis contains the acquisition energy component).

Appendix V-A contains four tables (V-A.1 through A.4) that present a detailed breakdown of the manufacturing system energy impacts for the 12 categories of recyclable materials extracted in each solid waste management scenario. In Appendix V-A, the manufacturing system energy impacts associated with each scenario are calculated by multiplying the tons of each recyclable material extracted by the manufacturing system energy coefficients in Table 5-1.

Table 5-2 presents the total system energy impacts for Scenarios A through D for MSW management (residential, institutional, and commercial waste management), special waste management (sludge, medical waste, C&D, harbor drift, and harbor dredge), wood waste combustion, and the energy impacts within the manufacturing system caused by the recycling of materials from the solid waste stream. The MSW and Special Waste Management data are taken from Tables 2-14 and 2-15, the wood waste combustion data is taken from Table 4-2, and the Manufacturing System numbers are taken from the tables in Appendix V-A.

There are two striking results illustrated in Table 5-2. The first is that energy savings from the use of secondary materials in manufacturing processes dominate the overall analysis of solid waste system energy impacts for Scenarios A, B, and C where between 34 - 35% of the wastestream is recycled. In the case of Scenarios A and B, the manufacturing system energy savings of 22.14 million MMBtu/year (i.e., 22.14 TBtu/year) and 22.34 million MMBtu/year, respectively, are 6% and 20% higher, respectively, than the net impact of the solid waste management system (i.e., a net generation of 20.84 million MMBtu and 18.55 million MMBtu/year of energy).

TABLE 5-2. Solid Waste, Wood Waste Combustion, and Manufacturing System Energy Summary for Scenarios A,B,C, and D (TBtu/year) [1].

Energy Component	Scenario A	Scenario B	Scenario C	Scenario D
MSW Management: Residential, Institutional, and Commercial Waste [2]				
Collection	0.49	0.53	0.53	0.47
Processing	4.14	4.20	2.27	5.36
Transport	0.06	0.05	0.07	0.07
Disposal	0.02	0.01	0.02	0.01
Energy Generation[3]	-27.62	-25.41	-3.65	-38.16
SUBTOTAL	-22.91	-20.62	-0.76	-32.25
Special Waste Management: Sludge, Medical Waste, C&D, Harbor Drift, and Harbor Dredge [2]				
Collection	0.59	0.59	0.59	0.59
Processing	2.44	2.44	2.44	2.44
Transport	0.01	0.01	0.01	0.01
Disposal	0.01	0.01	0.01	0.01
Energy Generation [3]	-0.99	-0.99	-0.99	-0.99
SUBTOTAL	2.07	2.07	2.07	2.07
MSW and Special Waste Management Total				
	-20.84	-18.55	1.31	-30.18
Manufacturing System:				
Energy Impacts from Recycling [4]	-22.14	-22.34	-21.92	-8.81
Wood Waste Combustion[5]	-5.14	-5.14	-5.14	-5.14
TOTAL[6]	-48.13	-46.03	-25.76	-44.14

Notes:

[1] A positive value indicates energy is used by the activity. A negative value indicates that energy is produced or saved by the activity.

[2] Taken from Tables 2-12 and 2-13.

[3] Includes energy recovery from landfill gas and incineration.

[4] Taken from Appendix V-A (recyclables diverted from waste stream multiplied by coefficients from Table 5-1).

[5] Taken from Tables 4-1 and 4-2.

[6] The energy associated with used motor oil and tires is not included in this table. An estimated 10.3 million gallons of used motor oil [*], and 3.5 million tires [**] are produced each year in NYC. The energy saved if the waste oil was recycled is approximately .5 TBtu/year. If the oil was used as blended fuel, about 1.1 MMBtu of useable heat would be produced assuming a boiler efficiency of 80%. The energy produced by using the tires as kiln fuel is about 1.2 TBtu/year, assuming a kiln efficiency of 80%. Collection, transportation and processing energy requirements would have to be deducted from these totals to include these contributions in this table.

* Varandani, M., NYCDEP, Nov. 1993.

**Moore, G., NYCDOS, Nov. 1993.

The second striking result is that the energy generation from MSW management is the dominant component in the entire system for all scenarios that utilize municipal waste combustors, namely Scenarios A, B, and D. The MSW energy generation values for these scenarios are 27.62 million MMBtu/year, 25.41 million MMBtu/year, and 38.16 million MMBtu/year, respectively. Clearly, these three scenarios had an average energy savings twice that of Scenario C, ranging from 44.14 to 48.13 million MMBtu/year compared with 25.76 million MMBtu/year in Scenario C.

While a look at only the energy impacts from the solid waste management system for the Scenario C (the no combustion scenario) indicates that this scenario is a slight net energy loser, the addition of manufacturing system energy impacts produces a net energy benefit of 20.62 million MMBtu/year, still well below the three combustion utilizing scenarios.

Scenario D is the exception to the dominance of the benefit of recycling over solid waste management. Owing to the relatively low recycling rate for this scenario (22%) and the relatively high rate of municipal waste combustion (65%), the energy savings associated with the recycling of wastes within the manufacturing system is lowest of all scenarios, and amounts to only 28% of the net energy generation value for the solid waste management system. For this scenario, it is the energy generated from municipal waste combustors that dominates the analysis. To minimize energy use in the solid waste management system, it was necessary to employ recycling, municipal waste combustors, and landfills, but the primary focus of this scenario was on combustion.

In all four scenarios, the energy generated from wood waste combustion remains constant at 5.14 million MMBtus. Annual wood waste combustion equals approximately 20% of the annual value of the total energy savings from secondary manufacturing in Scenarios A, B, and C, 21.92 to 22.34 million MMBtu respectively, and is close to 60% of the 8.81 million MMBtu annual value for energy savings from secondary production in Scenario D.

If we examine the waste streams handled in Scenarios A, B, C, and D, we observe the following ranges of average energy use per ton of materials handled. A negative number indicates that this form of management actually generates more energy than it requires in its management:

<u>Waste Stream</u>	<u>Energy Average Btu/ton</u>
Recyclables	3.44 to 3.74E + 05
Compostables	4.39 to 5.76E + 05
Combustibles	-6.22 to 6.71E + 06
Landfill	-1.47 to 1.71E + 06
Ash Landfill	1.31E + 04

Thus, municipal waste combustion generates more average energy than any of the other waste management options.

To put the results from this analysis into context, we can compare the energy impacts from the management of solid waste from New York City to energy consumption statistics for New York State. The estimated primary consumption of energy by the entire New York State in 1989 was 3821 million MMBtu (3821 TBtu).² Therefore, in the case of Scenario B, the energy savings associated with the recycling of New York City's waste -- 22.34 million MMBtu/year -- is 0.58% of total, annual energy consumption for the entire State. Add to this the energy generated from woodwaste combustion and the percentage rises to 0.72%. The net energy impact calculated for the entire system in the case of Scenario B -- 46.03 million MMBtu/year generated/saved -- is 1.20% of the total annual consumption of energy for the State. While small in comparison to total energy use for the State, the absolute quantity is certainly not insignificant.

SPATIAL ANALYSIS OF ENERGY IMPACTS OF TWO NEW YORK CITY PLANNING SCENARIOS

The choice of solid waste management options creates impacts on energy use and production within and outside boundaries of the New York City. To examine the spatial incidence of both energy use and recovery for the solid waste management system, and the virgin and recycling manufacturing systems affected by the City's plan, we have developed a methodology for assessing the spatial analysis of such impacts. This methodology, and its application to two planning scenarios are described below.

Within this description, we refer to several tables containing data input for, and results from, the spatial analysis. The following is an overview of these tables:

Table: **Table 5-3. Summary of Estimates Used in Spatial Analysis for Recycling Production in Regions 1, 2, 3, and 4.**

Function: Presents the assumptions used in predicting where each of ton of recyclable material from the scenario will be recycled into a new product.

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² New York State Energy Office, New York State Annual Energy Review: Energy Consumption, Supply and Price Statistics, 1970-1989.

Table: **Table 5-4. Summary of Estimates Used in Spatial Analysis for Virgin Production in Regions 1, 2, 3, and 4.**

Function: Presents the assumptions used in predicting where each ton of virgin-based product manufacturing will be displaced by the production of new product from recycled materials.

Table: **Table V-B.1. Spatial Analysis, Recycled Manufacturing-Region 1.**
(Appendix V-B)

Function: Calculates energy use associated with the recycling of materials from Scenario B, in Region 1 -- New York City (the first of four regions examined in the spatial analysis, explained below). The tons of recyclables recycled in this region is based on the assumptions presented in Table 5-3. The energy data is taken from the material and energy tables for recycling manufacturing in Appendix III.

Tables V-B.3, B.5, and B.7 are the same for Regions 2 (New York State), 3 (United States), and 4 (outside the United States), respectively.

Note: these spreadsheets are presented for Scenario B only.

Table: **Table V-B.2. Spatial Analysis, Virgin Manufacturing-Region 1.**
(Appendix V-B)

Function: Calculates energy associated with the manufacture of products from virgin materials in Region 1 *that will not be used* owing to the displacement of virgin production by recycling of materials from Scenario B. The tons of virgin production displaced in this region is based on the assumptions presented in Table 5-4. The energy data is taken from the material and energy tables for virgin manufacturing in Appendix III.

Tables V-B.4, B.6, and B.8 are the same for Regions 2 (New York State), 3 (United States), and 4 (outside the United States), respectively.

Note: these spreadsheets are presented for Scenario B only.

Table: **Table 5-5. Results of Spatial Analysis for Regions 1-4, For Scenario B.**

Function: This table presents the results of the spatial analysis for Scenario B, including solid waste system and manufacturing system impacts.

Table: **Table 5-7. Results of Spatial Analysis for Regions 1-4, For Scenario D.**

Function: This table presents the results of the spatial analysis for Scenario D, including solid waste system and manufacturing system impacts.

Spatial Analysis Methodology

The Solid Waste Management System. The current New York City solid waste planning scenarios include only facilities that are slated to be built within the jurisdictional boundaries of New York City. Consequently energy needed to run solid waste management facilities will be derived locally, steam produced at municipal waste combustors will be consumed locally, and electricity produced by municipal waste combustors will be fed into the grid of the utility that serves New York City (Consolidated Edison).

Therefore, the spatial analysis of the solid waste management system is rather straightforward -- the spatial incidence of all energy use and energy recovery will be within New York City.

The Virgin and Recycled Manufacturing Systems. We begin the methodology to assess the spatial incidence of energy impacts associated with virgin/recycled manufacturing systems with an assumption that the demand for the end-products analyzed (i.e., the products that are made from virgin and recycled raw materials) does not vary when the product is made with either virgin or recycled material. We further assume, when an additional quantity of recycled material is diverted from the solid waste management system, two effects will occur: a corresponding, additional quantity of product will be made from the recycled material *and* a corresponding, additional quantity of virgin product will not be made (i.e., will be displaced).

Determining the location of both the reuse of New York City's recycled materials and the location of displaced virgin manufacturing is not straightforward. Substantial uncertainties surround predicting where the recycled materials will be reused, and where virgin manufacturing will be displaced. Therefore, the spatial analysis of manufacturing system energy impacts can only be conducted in scenario analysis fashion using a specific set of facilities and recovered materials. We use this scenario approach to develop a spatial analysis of two New York City planning scenarios, B

and D. Scenario B was chosen because it approximates one selected by the City for implementation. Scenario D was chosen because it has a relatively low recycling rate and a high combustion rate. The results of the two scenarios will be compared later on in this section.

In our analysis, we define four spatial regions:

- Region 1 - within New York City
- Region 2 - outside New York City and within New York State
- Region 3 - outside New York State and within the U.S.
- Region 4 - outside the U.S.

For each region, we can predict the net energy effect from both an increase in recycled manufacturing and a decrease in virgin manufacturing for all materials studied by solving the equation:

Net energy impact for Region N =

Increase in recycled system energy use in Region N - Decrease in Virgin System Energy Use in Region N

Given this framework, our analysis is conducted in several steps, as follows:

- Step 1: From Scenario B and D of the New York City GEIS, we determined the types and quantities of recycled materials in the New York City wastestream that are targeted for diversion in the year 2000 (See Table 2-16).
- Step 2: For each recyclable material, we converted the quantity of material into a corresponding quantity of recycled product that can be made from the material (e.g., from 1 ton of waste aluminum we can make 0.9 tons of molten aluminum after accounting for the removal of impurities and production losses).
- Step 3: Using existing and projected recycling plant location and capacity data, we developed a scenario that reflects likely mixes of geographical locations for the recycling of these materials. Since recyclable material is commonly transported across state and national lines, we make informed judgments as to where these materials are destined. For example, despite the fact that several Canadian mills are planning to add new de-inking capacity for the recycling of newsprint, and a large newsprint recycling mill is planned for northern New York, it is conceivable that if the export market for newspaper is strong at the time that these mills come on line, New York City will still send much of its ONP out of the Port of New York.

Table 5-3 summarizes the assumptions that were used to perform this analysis and indicates the source documents that formed the basis of the assumptions. The documents consist primarily of recycling market studies performed for or by New York State Department of Economic Development and New York City Department of Sanitation (see Table 5.3 for references). These sources document existing and projected recycling capacity for the City and the State. We supplemented these documents with U.S. and international market data gathered to perform the transportation analysis. The same set of assumptions were used to analyze spatial impacts for Scenarios B and D.

Since the scenarios model the New York City solid waste management system in the year 2000, we began by projecting recycling capacity in New York City for the year 2000. We assumed that this capacity would be completely filled by recyclables generated within the boundaries of the City (i.e., those materials accounted for in the scenarios). Next, we projected recycling capacity in New York State for the year 2000 for each material. Since capacity within New York State, but outside the City, likely will be filled with waste from numerous cities and towns, we must make an assumption to predict the quantity of New York State capacity that will be filled by recyclables from the City. In most cases, we assume 50% New York City waste and the remainder from other municipalities.

We developed our capacity assumptions using similar reasoning for Region 3 -- within the U.S. (excluding New York State). Since large quantities of waste paper are exported from the Port of New York, we assumed that a relatively large percentage of waste paper (OCC, ONP, office paper, mixed paper) from the scenarios are exported out of the country for recycling. All assumptions are presented in Table 5-3.

- Step 4: Using the number of tons of each product that will be made from the recyclables diverted from the New York City wastestream (from Step 2), we assumed that an equal amount of virgin product is displaced. Based on the material and energy data developed in this study, we have calculated the quantity of raw and intermediate material needed to produce that amount of product, and energy needed to extract and produce the appropriate amount of raw, intermediate, and final product.
- Step 5: Based on our assessment of geographical locations of raw material extraction, intermediate, and final product manufacture, we make certain assumptions regarding the quantity of, and location where virgin manufacturing processes are likely to be displaced. These

assumptions are based primarily on the number and magnitude of raw material extraction and virgin manufacturing facilities in each region.

To illustrate, there currently is no manufacturing of virgin linerboard in New York City or New York State, and approximately 20 million tons of virgin linerboard were manufactured in the United States as a whole in 1991.³ Based on this information, we assumed that all virgin production displacement resulting from the recycling of OCC would occur within the U.S., outside of New York. In the case of bauxite mining for aluminum production, since 98% of bauxite/alumina used in the U.S. is imported, we assumed that bauxite mining displacement would occur outside the U.S.

Table 5-4 summarizes the estimates and source documents used for the spatial analysis of energy impacts of virgin manufacturing. The same set of assumptions were used to analyze spatial impacts for Scenarios B and D.

- Step 6: Using the manufacturing system energy data developed in this study (Sections 3 and 4), and the spatial assumptions documented in Tables 5-3 and 5-4, we calculated for each region: a) the increase in energy use from increased recycled manufacturing; b) the decrease in energy from decreased virgin manufacturing; and c) the net impact on the region that is the sum of (a) and (b).
- Step 7: Finally, we combined the solid waste management energy data with energy use data for recycling manufacturing. Since all solid waste management energy use and recovery is projected to occur within New York City (Region 1), we added all SW system energy impacts to this Region.

The methodology used in the spatial analysis differs in three respects from that of the manufacturing energy analysis, and, therefore, from the global analysis of the New York City SW system energy impacts. First, in the spatial analysis, process energy has not been allocated to co-products (i.e., useful products that are produced in tandem with the product studied) because the spatial analysis accounts for all the energy needed in a region for a particular production process. Subtracting co-product energy would result in reporting less energy than is necessary for production processes.

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³ Based on a projection contained in the American Paper Institute Paper and Paperboard Wood Pulp Capacity, 1988-1991, December 1989.

Second, transportation energy is not included in the spatial analysis because transportation occurs inter-regionally and is not allocable to a region in the same fashion as production energy. Since transportation energy is only a small fraction of total production system energy use, its omission does not materially affect the overall outcome of this analysis. These two changes result in different bottom-line energy savings in the global and spatial analyses (e.g., the totals reported on Table 5-2 versus Table 5-5 and 5-7). The omission of co-products energies in particular tends to increase the energy coefficients reported in Table 5-1, which increases the manufacturing energy saved from the use of recyclables. For example, excluding credit for co-product process energies increases virgin HDPE, LDPE, and PET production 18, 19, and 13 MMBtu/ton, and steel production over 2 MMBtu/ton. This causes overall energy savings to be greater in the spatial analysis of Scenarios B and D than in the global analysis.

Third, to make the spatial analysis energy tables more readable, the Process Fuel Consumption columns have been consolidated slightly: diesel fuel is added in the Oil column; coke and coke breeze are accounted for in the Coal column, and the remaining fuels other than natural gas are reported in the Other column. These numbers were read into the spatial analysis table, from the material and energy tables, in units of Btus.

Results

Appendix V-B contains the detailed spreadsheets used to analyze spatial incidence of manufacturing system impacts for Scenario B.⁴ The Tables in Appendix V-B are arranged as follows:

Table V-B.1 Spatial Analysis, Recycled Manufacturing-Region 1

Table V-B.2 Spatial Analysis, Virgin Manufacturing-Region 1

Table V-B.3 Spatial Analysis, Recycled Manufacturing-Region 2

Table V-B.4 Spatial Analysis, Virgin Manufacturing-Region 2

Table V-B.5 Spatial Analysis, Recycled Manufacturing-Region 3

Table V-B.6 Spatial Analysis, Virgin Manufacturing-Region 3

Table V-B.7 Spatial Analysis, Recycled Manufacturing-Region 4

Table V-B.8 Spatial Analysis, Virgin Manufacturing-Region 4

A summary of the results from these tables are presented in Table 5.5 for Scenario B.

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⁴ A similar set of spreadsheets was generated for Scenario D, however, we do not include them in the report.

Table 5-3. Summary of Estimates Used in Spatial Analysis for Recycled Production in Regions 1, 2, 3, and 4.

Recyclable Material	Region	Estimated Recyclable Use		Source	Description of Estimate Basis
		Rate (tons/yr)			
OCC	1	0	1		
	2	372,000	1		Approx. 744,000 tpy capacity by 2000. Assumed 50% filled by NYC waste [1]
	3	0	1		
	4	321,295	1		1989 OCC exports from NYS total 751,000 tpy. Assumed remaining OCC exported from Port of NY.
	Total	693,295			
ONP	1	60	3		Projected de-inking mill in NYC, Ponderosa Fibers of America to use 60 tpy ONP.
	2	172,000	1		Projected 230,000 tpy ONP capacity by 2000: 1995/96 NYS de-inking mill - Jefferson Smurfit. Assumed 75% of this capacity filled by NYC ONP.
	3	0	1		
	4	197,828	1		Projected 450,000 exported from Port of NY in 1995. Assumed all remaining ONP exported.
	Total	369,888			
Office Paper	1	0	4		
	2	43,800	4		Total NYS P/W capacity - 1,314,000 tpy. 4 of 9 mills projected to use 1% post-consumer office waste. Assumed 75% will be NYC waste paper.
	3	136,234	4		Assumed 50% of remaining waste used in U.S..
	4	136,234	4		Assumed 50% of remaining waste exported from Port of NY.
	Total	316,268			
Mixed Paper (inc. magazine (OMG)/glossy)	1	40	3		Projected de-inking mill in NYC, Ponderosa Fibers of America to use 60 tpy OMG
	2	150,750	1		See note 2.
	3	125,469	1		229 tpy exported from NYS. Assumed 50% of remaining paper used in U.S..
	4	125,469	1		Assumed 50% of remaining paper exported from Port of NY.
	Total	401,728			
HDPE Containers	1	4,700	1		Utility Plastics Co. in NYC using 14,000 tpy HDPE, PET, and PVC.
	2	37,474	1		11 plastics recycling plants in NYS. Assumed that 50% of the remainder is used in NYS.
	3	37,475	1		Assumed 50% of remainder used elsewhere in U.S.
	4	0	1		
	Total	79,649			
LDPE films and bags	1	0	2		
	2	16,269	2		3250 tpy of LDPE recycled by N. American Plastics Corp. in NYS, plus 11 other plastics recycling plants in NYS. Assumed that 50% used in NYS.
	3	16,270	2		Assumed 50% used in NYS.
	4	0	2		
	Total	32,539			
PET Containers	1	4,700	2		Utility Plastics Co. in NYC using 14,000 tpy HDPE, PET, and PVC.
	2	14,249	2		11 plastics recycling plants in NYS. Assumed that 50% of the remainder is used in NYS.
	3	14,250	2		Assumed 50% of remainder used elsewhere in U.S.
	4	0	2		
	Total	33,199			

Table 5-3 (Continued). Summary of Estimates Used in Spatial Analysis for Recycled Production in Regions 1, 2, 3, and 4.

Recyclable Material	Region	Estimated Recyclable Use Rate (tons/yr)	Source	Description of Estimate Basis
Glass	1	0	2	
	2	74,500	2	Projected cullet use rate by 4 NYS plants, if used 70% cullet - 119,000 tpy. Assumed all waste glass will be going to these plants.
	3	0	2	
	4	0	2	
	Total	74,500		
Aluminum (cans and foil)	1	0	1	No NYC capacity.
	2	0	1	No NYS capacity
	3	45,548	1	Assumed that all aluminum used in U.S., outside of NYS.
	4	0	1	
	Total	45,548		
Steel (cans and scrap)	1	0	1	
	2	93,095	1	400,000 tpy mini-mill capacity for steel cans and 135,000 capacity for scrap in NYS. Assumed 50% of NYC steel waste going to NYS mills.
	3	93,095	1	Assumed 50% of NYC steel waste going to other U.S. states.
	4	0	1	
	Total	186,190		

Sources:

- [1] Office of Recycling Market Development, New York State of Economic Development "1990 Status of the Markets Report for: Paper, Metals, Glass, Plastics and Used Oil". March 1991.
- [2] Cal Recovery Systems, Inc. "Recyclables Market Assessment for New York City," for the New York City Department of Sanitation, May 1991.
- [3] The Paper Stock Report, April 1991.
- [4] Mt. Auburn Associates. "Policy Options for Promoting the Demand for Recycled Products in New York State: Case Studies of Products Make from Used Office Paper, Used Oil, and Scrap Tires,". Prepared for NYS DED. February 1991.

Notes:

- [1] Projected capacity: 744,000 tpy: 1989 capacity 294,000 tpy, conversion of mill in Niagra Falls recycled medium mill - 150,000 tpy, new mill projected (Westfield Containerboard in Chataqua County) - 300,000 tpy.
- [2] In 1989, 101,000 tpy mixed paper capacity in NYS and projected 100,000 tpy OMG capacity in 1995/96 - NYS deinking mill, built by Smurfit News Assumed 50% capacity filled by NYC paper.

Table 5-4. Summary of Estimates Used in Spatial Analysis for Virgin Production in Regions 1, 2, 3, and 4.

Virgin Product	Processes	Process Output	Region	Change in Process Output in Region (tons/yr)	Source	Description of Estimate Basis
Linerboard	wood harvesting through boardmaking	linerboard	1	0	[1]	No virgin linerboard production in NYC or NYS. Assumed displaced in U.S.
			2	0		
			3	602,865		
			4	0		
			Total	602,865		
Newsprint	wood harvesting through TMP prod.	TM pulp (air dry)	1	0	[1]	No TMP production in NYC or NYS. U.S. imports newsprint. Assumed 50% in U.S. and 50% outside U.S.
			2	0		
			3	131,335		
			4	131,335		
			Total	262,670		
	wood harvesting through bleached kraft pulp prod.	bl.kraft pulp (air dry)	1	0		Based on assumption above.
			2	0		
			3	6,912		
			4	6,912		
			Total	13,824		
	forming and drying	newsprint	1	0		Based on assumption above.
			2	0		
			3	158,522		
			4	158,522		
			Total	317,044		
Printing/Writing Paper	wood harvesting through papermaking	printing/writing paper	1	0	[1]	One virgin, integrated P/W mill in NYS, 575 tpd. Assumed that 50,000 tpy displaced.
			2	50,000		
			3	227,063		
			4	0		
			Total	277,063		
	chlorine production	chlorine	1	0	[1]	No chlor-alkali plants in NYC or NYS. Assumed that all chlorine and caustic produced outside of NYS, but within U.S.
			2	0		
			3	9,667		
			4	0		
			Total	9,667		
	caustic production	caustic	1	0		Based on assumption above.
			2	0		
			3	15,921		
			4	0		
			Total	15,921		
Folding Boxboard	wood harvesting through boardmaking	folding boxboard	1	0	[1]	One 65 tpd folding boxboard mill in NYS. Assumed all production displaced within U.S.
			2	0		
			3	391,081		
			4	0		
			Total	391,081		

Table 5-4 (Continued). Summary of Estimates Used in Spatial Analysis for Virgin Production in Regions 1, 2, 3, and 4.

Virgin Product	Processes	Process Output	Region	Change in Process Output in Region (tons/yr)	Source	Description of Estimate Basis
HDPE Pellets	petroleum extraction	crude oil	1	0	[2]	Approximately 50% of oil consumed in U.S. is imported and 50% acquired domestically. Assumed 50% of oil was domestic, 50% imported, but none from within New York State.
			2	0		
			3	139,147		
			4	139,147		
			Total	278,294		
	natural gas extraction	natural gas (cf)	1	0	[2]	Less than 10% of natural gas consumed in U.S. is imported. Assumed all natural gas for HDPE production is domestic, but none from NYS.
			2	0		
			3	2,533,503,877		
			4	0		
			Total	2,533,503,877		
	oil and gas refining through resin production	HDPE pellets	1	0	[2]	Assumed all HDPE production outside NYS but within U.S.
			2	0		
			3	79,649		
			4	0		
			Total	79,649		
LDPE Pellets	petroleum extraction	crude oil	1	0	[2]	Approximately 50% of oil consumed in U.S. is imported and 50% acquired domestically. Assumed 50% of oil was domestic, 50% imported, but none from within New York State.
			2	0		
			3	58,518		
			4	58,517		
			Total	117,035		
	natural gas extraction	natural gas (cf)	1	0	[2]	Less than 10% of natural gas consumed in U.S. is imported. Assumed all natural gas for LDPE production is domestic, but none from NYS.
			2	0		
			3	1,065,453,683		
			4	0		
			Total	1,065,453,683		
	oil and gas refining through resin production	LDPE pellets	1	0	[2]	Assumed all LDPE production outside NYS but within U.S.
			2	0		
			3	32,539		
			4	0		
			Total	32,539		
PET Pellets	petroleum extraction	crude oil	1	0	[2]	Approximately 50% of oil consumed in U.S. is imported and 50% acquired domestically. Assumed 50% of oil was domestic, 50% imported, but none from within New York State.
			2	0		
			3	68,259		
			4	68,259		
			Total	136,518		
	natural gas extraction	natural gas (cf)	1	0	[2]	Less than 10% of natural gas consumed in U.S. is imported. Assumed all natural gas for PET production is domestic, but none from NYS.
			2	0		
			3	264,519,066		
			4	0		
			Total	264,519,066		

Table 5-4 (Continued). Summary of Estimates Used in Spatial Analysis for Virgin Production in Regions 1, 2, 3, and 4.

Virgin Product	Processes	Process Output	Region	Change in Process Output in Region (tons/yr)	Source	Description of Estimate Basis
PET Pellets (cont.)	oil and gas refining through resin production	PET pellets	1	0	[2]	Assumed all PET production outside NYS but within U.S.
			2	0		
			3	33,199		
			4	0		
			Total	33,199		
Molten Glass	sand mining	sand	1	0	[3]	Because all virgin glass production will b displaced in NYS, assumed all sand fro NYS.
			2	39,139		
			3	0		
			4	0		
			Total	39,139		
	limestone mining/proc.	limestone	1	0	[3]	Because all virgin glass production will b displaced in NYS, assumed all limeston from NYS.
			2	11,043		
			3	0		
			4	0		
			Total	11,043		
	feldspar mining/process.	feldspar	1	0	[3]	Over 70% of U.S. feldspar mined in NC. Assumed all feldspar from outside NYS, but within U.S.
			2	0		
			3	3,355		
			4	0		
			Total	3,355		
	soda ash mining/proc.	soda ash	1	0		Assumed all soda ash from outside NYS, but within U.S.
			2	0		
			3	12,301		
			4	0		
			Total	12,301		
	cullet crushing through melting	molten glass	1	0	[4]	Assumed all virgin glass production will displaced within NYS (at glass plants indicated in recycled summary), outside of NYC.
			2	74,550		
			3	0		
			4	0		
			Total	74,550		
Molten Aluminum	bauxite mining/process.	bauxite	1	0	[5]	Over 98% of bauxite is imported. Assumed all comes from outside U.S.
			2	0		
			3	0		
			4	183,873		
			Total	183,873		
	caustic soda production	caustic soda	1	0	[5]	Assumed aluminua production split 70% domestic and 30% imported, therefore the same for caustic.
			2	0		
			3	3,526		
			4	1,511		
			Total	5,037		

Table 5.4. (Continued) Summary of Estimates Used in Spatial Analysis for Virgin Production in Regions 1, 2, 3, and 4

Virgin Product	Processes	Process Output	Region	Change in Process Output in Region (tons/yr)	Source	Description of Estimate Basis
Molten Alum (cont.)	Bayer process	alumina	1	0	[5]	Split alumina 70% domestic and 30% imported.
			2	0		
			3	55,961		
			4	23,984		
			Total	79,945		
	Hall-Heroult process		1	0		Assumed all virgin aluminum production will be displaced within the U.S. but outside NYS.
			2	0		
			3	40,997		
			4	0		
			Total	40,997		
Molten Steel	iron ore mining	raw feed ore	1	0	[6]	Iron ore primarily mined in MN and MI, therefore outside NYS but within U.S.
			2	0		
			3	39,448		
			4	0		
			Total	39,448		
	iron ore mining/process.	iron ore pellets	1	0	[6]	Iron ore primarily mined in MN and MI, therefore outside NYS but within U.S.
			2	0		
			3	240,983		
			4	0		
			Total	240,983		
	limestone mining/proc.	limestone	1	0	[6]	Assumed virgin steel production will be displaced within the U.S. but outside NYS, therefore same for limestone.
			2	0		
			3	72,738		
			4	0		
			Total	72,738		
	lime processing	lime	1	0	[6]	Assumed virgin steel production will be displaced within the U.S. but outside NYS, therefore same for lime.
			2	0		
			3	10,688		
			4	0		
			Total	10,688		
	coal mining/process.	coal	1	0	[6]	Primary source of coking coal is KT.
			2	0		
			3	143,711		
			4	0		
			Total	143,711		
	coke, sinter and pellet production through molten steel (BOF)	steel	1	0		Assumed all virgin steel production will be displaced outside NYS but within U.S.
			2	0		
			3	187,503		
			4	0		
			Total	187,503		

Table 5-4 (Continued). Summary of Estimates Used in Spatial Analysis for Virgin Production in Regions 1, 2, 3, and 4.

Virgin Product	Processes	Process Output	Region	Change in Process Output in Region	Source	Description of Estimate Basis
				(tons/yr)		
Aggregate	gravel mining/processing	aggregate	1	0		Assumed all virgin aggregate production will be displaced within NYS but outside New York City.
			2	555,163		
			3	0		
			4	0		
			Total	555,163		

Sources:

- [1] Office of Recycling Market Development, New York State of Economic Development "1990 Status of the Markets Report for: Paper, Metals, Glass, Plastics and Used Oil". March 1991.
- [2] Refer to "Notes," Table III-B.5.
- [3] Refer to "Notes," Table III-B.6.
- [4] Refer to "Notes," Table III-B.7.
- [5] Cal Recovery Systems, Inc. "Recyclables Market Assessment for New York City," for the NYC Department of Sanitation. May 1991.
- [6] Refer to "Notes," Table III-B.8.

TABLE 5-5. RESULTS OF SPATIAL ANALYSIS FOR REGIONS 1-4, FOR SCENARIO B.

Region	SW System/ Recy./Virgin Manufacturing	Electricity (kWh/yr)	Steam (lbs/yr)	Process Fuel Consumption				Total (MMBtu/yr)
				Oil (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other[1] (MMBtu/yr)	
1 = NYC	SW System [2]						-1.85E+07	
	Recycled [3]	9.46E+06	7.42E+05					
	Virgin [4]							
	Net Energy[5]	9.46E+06	7.42E+05					
	Net MMBtu[6]	9.93E+04	1.04E+03				-1.85E+07	-1.84E+07
2 = NYS (excluding NYC)	Recycled	5.39E+08	6.04E+09	8.91E+02	2.89E+08	3.17E+02	1.14E+02	
	Virgin	-2.57E+07	-6.54E+08	-6.58E+05	-3.44E+08	0.00E+00	-1.86E+04	
	Net Energy	5.13E+08	5.38E+09	-6.57E+05	-5.51E+07	3.17E+02	-1.85E+04	
	Net MMBtu	5.39E+06	7.53E+06	-9.84E+04	-5.68E+04	7.93E+03	-1.85E+04	1.28E+07
3 = U.S. (excluding NYS)	Recycled	2.82E+08	2.10E+09	8.91E+02	2.77E+08	3.17E+02	1.14E+02	
	Virgin	-1.23E+09	-1.98E+10	-2.00E+07	-3.82E+09	-1.11E+05	-5.16E+06	
	Net Energy	-9.47E+08	-1.77E+10	-2.00E+07	-3.54E+09	-1.11E+05	-5.16E+06	
	Net MMBtu	-9.94E+06	-2.48E+07	-3.00E+06	-3.65E+06	-2.77E+06	-5.16E+06	-4.93E+07
4 = Outside of U.S.)	Recycled	4.47E+08	5.98E+09					
	Virgin	-2.84E+08	-8.43E+08	-1.51E+06	-2.42E+08	-1.13E+03	-1.22E+03	
	Net Energy	1.63E+08	5.14E+09	-1.51E+06	-2.42E+08	-1.13E+03	-1.22E+03	
	Net MMBtu	1.71E+06	7.19E+06	-2.26E+05	-2.50E+05	-2.82E+04	-1.22E+03	8.40E+06

Net Energy for Regions 1 through 4:

-4.65E+07

Notes:

[1] Other Process Fuels refers to remaining fuels other than natural gas, coal, or oil, such as gasoline, propane, etc.

[2] From Table 5-2. Includes MSW and Special Waste management, energy use and recovery.

[3] Energy used in the region to manufacture new products from recyclables.

[4] Energy use displaced (i.e., not used) in region by manufacture of new products from recyclables.

[5] The sum of recycling energy use and virgin energy displaced for region, in units of kWh/yr electricity, pounds/yr steam, etc.

[6] The sum of recycling energy use and virgin energy displaced for region, in units of MMBtu/yr.

Based on the results of Scenario B reported in Appendix V-B, a simple rank ordering of the regions, according to energy use in recycled manufacturing and energy displaced in virgin manufacturing, is as follows:

Table 5-6. Increased, Decreased, and Net Energy Use in Recycled Manufacturing, in Million MMBtu/year by Region for Scenario B:

	Increased	Decreased	SW System	Net
Region 1 New York City	0.1	0.0	-18.5	-18.4
Region 2 New York State, (excluding New York City)	14.4	1.7		12.7
Region 3 U.S., (excluding New York State)	6.2	55.5		-49.3
Region 4 Outside U.S.	13.1	4.7		8.4

Sources: Tables V.B1-B.B6, in Appendix V, and Table 2-11.

Referring to Table 5-5, the results indicate that New York City (Region 1) will realize net energy recovery of 18.4 million MMBtu per year (i.e., 18.4 TBtu/yr). The primary contribution to this number comes from the solid waste system component -- 18.5 million MMBtu/year -- which is the net quantity of energy generated by the SWM system modeled in this scenario. We expect that a very small amount of ONP and mixed paper will be recycled in New York City in the year 2000, contributing a small quantity of energy use in the region.

New York State (excluding New York City) is projected to realize a net increase in energy use of 12.7 million MMBtu/year from the diversion of recyclables from the New York City wastestream in the year 2000. Electricity use is projected to increase by 513 million kWh/year (Tables V-B.3 and 4). With the exception of aluminum, we project that some fraction of all recyclable materials analyzed will be recycled in the State. As can be seen in Table 5-6, the projected increase in State energy use from recycling manufacturing plants is 14.4 million MMBtu/year. The greatest contribution to this component of the region's energy balance comes from the recycling of paper materials, particularly OCC. The recycling of all paper adds 10.86 million MMBtu of energy use to the region. We project that a small fraction of displaced production of virgin printing and writing paper (50,000 out of 277,000 total tons/year displaced) and all displaced virgin glass manufacturing will occur in New York State. Therefore, as seen in Table 5-6, 1.7 million MMBtu of energy per year

is expected to be displaced in the region -- a small quantity of energy compared to the estimated 14.4 million MMBtu increase from recycled manufacturing.⁵

In Region 3 -- the United States (excluding New York State and New York City) -- we project that energy displaced in virgin manufacturing will far outweigh new energy demand from recycled manufacturing. The net result is a decrease of 49.4 million MMBtu/year in energy consumed in the region. In addition, virgin energy displacement in Region 3 exceeds by far that for all other regions. This result is based on our projections that most virgin manufacturing displaced as a result of the introduction of New York City recyclables into the economy will take place outside of New York State, but within the U.S. Again, these projections are based on our assessment of the geographic distribution of a variety of raw material extraction and manufacturing operations and assumptions concerning the likely incidence of virgin manufacturing displacement.

According to our analysis, Region 4 (outside U.S.) realizes the highest increase in energy use within the recycling sector and second highest (next to Region 3) reduction in energy use within the virgin sector. With respect to recycled manufacturing, we assume that a large percentage of waste paper is recycled outside of the U.S. This assumption is based on the high rate of waste paper export from the Port of New York. The recycling of this paper in Region 4 carries with it a significant energy demand -- 13.1 million MMBtu/year.

Scenario D, the high combustion scenario, provides an interesting contrast to the results of the spatial analysis of Scenario B. The results of the spatial analysis of energy impacts for this scenario are presented in Table 5-7. We use a common set of assumptions of spatial incidence of recycled manufacturing and virgin manufacturing displacement to analyze Scenarios B and D; however, fewer materials are recycled in Scenario D, thus overall energy use for recycled manufacturing and energy savings from displacement of virgin manufacturing will be smaller than in Scenario B. Our discussion of the spatial impacts of Scenario D is confined to a comparison of the results of the two Scenarios.

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⁵ Based on our assumptions, we project that 656,000 tons/year of recycled paper will be produced in New York State from waste paper diverted from New York City's solid waste management system, and 50,000 tons/year of virgin paper production will be displaced. Unlike most virgin paper manufacturing plants, paper recycling plants are exclusively or largely reliant upon purchased electricity or fossil fuels for their energy needs. Many virgin plants generate part of their own energy from the combustion of process or purchased waste materials. While our estimates are necessarily rough, any increase in recycled paper production and decrease in virgin production will likely result in a shift from waste-based energy to fossil fuel-based energy consumption.

TABLE 5-7. RESULTS OF SPATIAL ANALYSIS FOR REGIONS 1-4, FOR SCENARIO D.

Region	SW System/ Recy./Virgin Manufacturing	Electricity (kWh/yr)	Steam (lbs/yr)	Process Fuel Consumption				Total (MMBtu/yr)
				Oil (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other[1] (MMBtu/yr)	
1 = NYC	SW System [2]						-3.02E+07	
	Recycled [3]	9.46E+06	7.42E+05					
	Virgin [4]							
	Net Energy[5]	9.46E+06	7.42E+05					
	Net MMBtu[6]	9.93E+04	1.04E+03				-3.02E+07	-3.01E+07
2 = NYS (excluding NYC)	Recycled	5.31E+08	6.04E+09	7.55E+02	1.54E+08	2.69E+02	9.65E+01	
	Virgin	-2.38E+07	-6.54E+08	-6.57E+05	-1.76E+08	0.00E+00	-9.54E+03	
	Net Energy	5.07E+08	5.38E+09	-6.56E+05	-2.25E+07	2.69E+02	-9.45E+03	
	Net MMBtu	5.32E+06	7.53E+06	-9.83E+04	-2.32E+04	6.72E+03	-9.45E+03	1.27E+07
3 = U.S. (excluding NYS)	Recycled	9.25E+07	1.05E+09	7.55E+02	7.00E+07	2.69E+02	9.65E+01	
	Virgin	-5.15E+08	-1.29E+10	-1.23E+07	-1.28E+09	-9.26E+04	-2.00E+06	
	Net Energy	-4.23E+08	-1.18E+10	-1.23E+07	-1.21E+09	-9.23E+04	-2.00E+06	
	Net MMBtu	-4.44E+06	-1.65E+07	-1.85E+06	-1.24E+06	-2.31E+06	-2.00E+06	-2.84E+07
4 = Outside of U.S.)	Recycled	1.10E+08	1.70E+09					
	Virgin	-1.06E+08	-3.17E+08	-4.73E+05	-5.16E+07	-2.40E+02	-2.65E+02	
	Net Energy	3.93E+06	1.38E+09	-4.73E+05	-5.16E+07	-2.40E+02	-2.65E+02	
	Net MMBtu	4.13E+04	1.93E+06	-7.08E+04	-5.32E+04	-6.00E+03	-2.65E+02	1.84E+06

Net Energy for Regions 1 through 4:

-4.39E+07

Notes:

[1] Other Process Fuels refers to remaining fuels other than natural gas, coal, or oil, such as gasoline, propane, etc.

[2] From Table 5-2. Includes MSW and Special Waste management, energy use, and recovery. Wood waste was not included in the spatial analysis as it is not recycled in the same manner as traditional recyclables. It is combusted to produce energy not a wood product.

[3] Energy used in the region to manufacture new products from recyclables.

[4] Energy use displaced (i.e., not used) in region by manufacture of new products from recyclables.

[5] The sum of recycling energy use and virgin energy displaced for region, in units of kWh/yr electricity, pounds/yr steam, etc.

[6] The sum of recycling energy use and virgin energy displaced for region, in units of MMBtu/yr.

Region 1 impacts for the two scenarios differ only by the energy impacts associated with the solid waste management system. As calculated in Section 2 (illustrated in Table 5-2), the net energy impact for Scenario D of the solid waste management system produced a relatively high net rate of energy recovery -- 30.2 million MMBtu/year. This impact results in a higher net energy recovery value for the region as a whole, 30.1 million MMBtu/year, compared to Scenario B (18.4 million MMBtu/year), when the solid waste management system value is combined with the small energy impacts of recycling.

Region 2 impacts are virtually identical for Scenarios B and D. However, because of the lower rate of recycling in Scenario D, the net impacts in Regions 3 and 4 are lower than those in Scenario B.

Overall, the higher combustion rate and lower recycling rate in Scenario D translates into a greater direct energy benefit to New York City in the form of energy recovery from combustion, virtually no difference in New York State, less energy saved within the U.S. (outside of New York State), and less energy consumed outside of the U.S. The following table presents these results:

Table 5-8. Comparison of Spatial Analysis Results for Scenarios B and D.

	Net Energy Impact (Million MMBtu/Year)	
	Scenario B	Scenario D
Region 1 New York City	-18.4	-30.1
Region 2 New York State, (excluding New York City)	12.8	12.7
Region 3 U.S., (excluding New York State)	-49.3	-28.4
Region 4 Outside U.S.	8.4	1.8
Total Energy Impacts	-46.5	-43.9

Section 6

CONCLUSIONS

Tracking the direct and indirect energy use and recovery through a solid waste system provides energy and waste planners with one quantitatively comparable perspective for choosing among management options. For statewide planning purposes, knowing where, how much, and what type of energy is required under alternative scenarios provides direct input in statewide forecasts, as well as insights into potential bottlenecks in implementing secondary materials manufacturing facilities that New York State may wish to promote. For local planners, energy requirements for specific collection systems, vehicles, processing, and disposal facilities is one variable in determining overall systems costs. Beyond the state and local levels, understanding energy implications of integrated systems represents one perspective (among many) in comparing the benefits of virgin versus secondary materials manufacturing. This, in turn, may inform the broader policy issue of whether and how government policy should direct manufacturing processes toward more efficient modes of production.

Understanding the interaction between waste management and energy use requires disaggregation of a management system into two components. The first component is direct energy use and recovery linked to collection, transport, processing and disposal of the waste materials. The second component comprises the indirect effects tied to transport and processing of materials recovered from the waste stream, plus energy displaced through displacement of virgin materials in product manufacturing. The summation of these two elements -- direct plus indirect -- yields an energy balance for a specified system.

Conducting this type of analysis requires the delineation of boundary conditions demarcating which energy flows will be included in the analysis. With each decision concerning collection, transport, processing, and substitution of recycled for virgin material, ripple effects are transmitted throughout the system. With each such shift, global and region-specific energy balances change. No single definition exists of the correct systems boundaries. In the end, our choice, like any choice, must meet the test of reason.

Once established, calculating a system balance is best handled through a scenario analysis capable of asking a series of "what if" questions. This is the role of the four New York City scenarios in this study, which provided the foundation for computing global and region-specific energy implications.

Keeping in mind the multitude of assumptions pertaining to both the solid waste management and secondary materials manufacturing analyses, our analysis suggests the following general conclusions:

- In comparing energy flows in collection, processing, transport, and disposal, it is the processing step that dominates energy use regardless of the mix of recycling, composting, combustion and landfilling that comprise a given system. In the four scenarios we examined, processing represents between 87 to 95.0% of energy use in the direct waste management system.
- Within the confines of the direct solid waste management system, exclusive of indirect (secondary manufacturing) effects, intensive use of combustion yields a relatively high net energy balance. This is the case even though combustion systems use substantial energy in their operation. In comparison to relatively modest combustion scenarios in which combustion handles 39 to 45% of the waste stream, a 63% combustion scenario adds approximately 50% to the system energy balance, after accounting for all uses and generation in the waste management system, including special wastes.
- With one minor exception, recycle manufacturing systems demonstrate greater energy efficiency than virgin systems. The range of these differences is enormous. At the high end is aluminum, for which the difference in virgin versus secondary production (the energy coefficient) is 128.42 MMBtu per ton of intermediate product. In the intermediate range (30 to 50 MMBtu) coefficients are products such as HDPE pellets, LDPE pellets, PET pellets. And at the lowest (under 5 MMBtu) are linerboard, boxboard, molten glass, and aggregate road base (the only negative coefficient). In all cases, it is the production process energy functions (versus collection, transportation, and preprocessing) that dominate the manufacturing systems energy requirements.
- With the exception of the combustion-intensive scenario and leaving aside wood waste combustion (which is handled separately in the scenario development), the indirect energy effects of diverting waste materials to secondary materials exceed the direct management systems. This difference ranges from a factor of 1.2 to 17.7. In other words, secondary manufacturing accounts for slightly more than half and up to 94% of the positive systems-wide energy balance. Thus, in management systems that rely moderately to heavily on recycling and composting, the bulk of the net energy benefits are attributable to the energy efficiency inherent in secondary materials manufacturing made possible by the recovery of materials from residential, institutional, and commercial waste streams. In contrast, in the combustion-intensive scenario, energy recovery dominates the energy balance. In this case, the direct system effects exceed those of the secondary manufacturing

effects by a factor of 3.4; i.e., the direct management system (and largely waste-to-energy) accounts for over two-thirds of positive systems balance.

- The spatial impacts of energy benefits are highly diffuse. Using the allocation methodology in this study, heavy reliance on combustion creates substantial localized energy benefits for New York City, exceeding that energy savings in the U.S. outside New York State. More modest levels of combustion change this profile. In this case, energy benefits are concentrated in the U.S. outside New York State, a result of the substantial and diffuse savings of secondary materials manufacturers that use New York City's recycled wastes as industrial feedstock.
- New York State outside New York City will feel the effects of energy use by new recycling industries, and this will offset the savings of displacing virgin production in the state. While the impacts statewide of diverting New York City's waste are small in absolute terms -- probably about 1% of statewide energy use -- localized and regional impacts may well be of some consequence. This would occur if, for example, major, new, electricity-intensive recycling industries co-locate in a single utility-service territory. Planning for such developments is a logical component of any statewide energy planning program.
- In sum, all four scenarios show a positive energy balance indicating the energy advantage of integrated systems versus reliance on one or a few technology options. That is, energy produced or saved exceeds the energy used to operate the solid waste system. The largest energy use impacts are attributable to processing, including materials separation and composting. Collection and transportation energy are relatively minor contributors. The largest two contributors to net energy savings are waste combustion and energy saved by processing recycled versus virgin materials. Scenarios A, B, and D, all featuring a combination of recycling and combustion with energy recovery, show a substantial positive balance of approximately twice that of the combustion-free Scenario C. Thus, notwithstanding the spatial distribution of energy benefits, a mix of waste management approaches is essential for maximizing system-wide energy benefits.
- From a planning perspective, energy requirements per ton of product for virgin versus recycle materials manufacturing is not only a matter of quantity, but also source and type -- purchased versus on-site, renewable versus fossil. Recycle paper products such as linerboard, printing/writing paper, and boxboard, require more purchased energy on a per-ton basis than their virgin counterparts. Moreover, the energy recovered on site from wood residues, which amounts to about 11-70% of total energy needs for these three paper products, is a renewable source unlike fossil-generated off site electricity

purchases. Other materials such as aluminum, plastics, and steel also use recover energy from on-site sources, though only in modest quantities and not from renewable sources. In any case, effective energy planning to meet the needs of future secondary materials industries requires consideration of source and type, in addition to total quantity.

The methodology and scenarios in this study provide a foundation for further exploration of the solid waste/energy interactions. The analytical framework is receptive to alternative assumptions, as well as new data on energy flows in both the solid waste management system and/or secondary materials manufacturing sector. Future applications of our approach promise to provide valuable insights into predicting how much, what type, and where energy impacts will occur as solid waste management systems continue to move from single facility to more integrated, and complex, configurations.

Finally, our experience in developing and applying our methodology points to the following five items for future research directions:

- **Market demand for recyclables.** Our analysis assumes all recyclable materials will find a market rather than be diverted to processing and disposal facilities. Given uncertainties in the development of secondary materials markets, sensitivity analysis under conditions of less than 100% marketability of recyclables merits further consideration.
- **Future regulatory requirements.** Air and water pollution standards, compost, sludge and ash classification, and revisions to landfill standards may affect the options available to waste managers. Incorporating such changes into future scenarios by altering diversion rates to various facility types would enable examination of consequences of future regulatory requirements.
- **Upgrading data sources.** While we believe all manufacturing data sources are the best available within the public domain, additional data development would strengthen future analyses. This is especially true for plastics recycling, where data was difficult to obtain and subject to early obsolescence because of rapid technological changes in the industry.
- **Expanding the covered wastes.** Future analyses would benefit from including additional components, especially polypropylene, PVC, and polystyrene plastics. Though small in volume terms, these represent potentially substantial energy implications on a systems-wide basis.
- **Indirect impacts within the solid waste management system.** Excluded from the analysis are energy implications of operating additional wastewater treatment facilities tied to higher rates of recycling in households and

institutions. Assessing these, and other such indirect effects of recycling, would add a valuable dimension to future systems studies.

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APPENDIX II-A

**DESCRIBING THE WASTEPLAN COLLECTION PLANNING
PROCESS**

APPENDIX II-A

DESCRIBING THE WASTEPLAN COLLECTION PLANNING PROCESS

GENERAL METHODOLOGY

There was a wealth of information available about many of the variables affecting costs and operations for New York City's collection and processing systems as they existed in 1990. Some of this information, such as total number of truck shifts by type of truck for each of the city's 59 sanitation districts and 12 sanitation zones, and the total number of households receiving containerized collection service was developed by various city departments. Primary among those departments were the Operations Planning Evaluations and Control unit (OPEC) and the Bureau of Cleaning and Collection (BCC) within the Department of Sanitation (DOS). These bureaus provided information about crew sizes, relay rates,¹ and costs of vehicle maintenance, among other information.

This information was applied toward the generation of a baseline analysis of the city's collection and processing operations in 1990. The goal of creating a baseline was to generate all the foundation input variables from which projected collection and processing systems could be modeled. The immediate goal of the baseline analysis² was reproducing the city's known operating and cost data using model inputs developed in the course of conducting the analysis. This calibration of the model, in which previously unknown variables were determined or assumed, created a set of baseline variables. These variables were then further modified in response to collection and processing requirements imposed on the planning process by mandated levels of recycling and waste prevention.

COLLECTION VARIABLES: DEFINING TRUCK LOADS PER DAY

Unlike other variables used in the calculation of energy consumed in the collection of solid waste, truck loads per day (i.e., the number of times each truck on the street is filled and then emptied) is not an input variable. Rather, it is a

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¹ Relaying is a system in which a full collection vehicle is brought back to a garage rather than delivered to a dumping site. The full vehicle is then delivered to its drop-off destination by a relay driver on the following shift. The relay rate affected calculations of collection hours per day, as will be described in a later section.

² This analysis is entitled: "New York City's Baseline Solid Waste and Recycling Collection Program Evaluation; Residential Curbside and Containerized Collections for Fiscal Year 1990," and is found in New York City Department of Sanitation, GEIS, Appendix 4-0: Baseline Analysis of Collection/Processing/Disposal System, 1992.

calculated output of the WastePlan model. The formula used to calculate truck loads per day is simple in form: total truck loads per day is the sum of the integral loads per day and the fractional loads per day. Integral loads per day is the integral value of the total number of loads each truck can handle in a day, and the fractional loads is the proportion of a full load to which a truck can be filled in the remaining time available after collecting as many full loads as possible. This equation can be represented as follows:

$$LPD = I_L + F_L$$

where LPD represents loads per day and I_L and F_L represent integral loads per day and fractional loads per day, respectively.

Values for both integral and fractional loads per day are derived by WastePlan from a complicated series of calculations based on values entered into the model. Tracing the chain of calculations from this final, simple equation for loads per day to an equation that uses nothing but input values results in the following equation:

$$LPD = \frac{CH}{\frac{cr \times C \times AU \times sof \times P \times w \times PU \times d}{sph \times AU \times G \times dv} + 2 \frac{dist}{mph} + q} + \frac{CH - 2 \times (2 \frac{dist}{mph} + q)}{\frac{cr \times C \times AU \times sof \times P \times w \times PU \times d}{sph \times AU \times G \times dv}}^{-1}$$

Symbols used in the above equation are defined below.

Symbol	Definition
CH	total collection hours per day
cr	compaction ratio of the collection vehicle
C	useable vehicle capacity
AU	total activity units targeted
sof	set-out rate for targeted materials
P	highest participation rate
w	collection weeks per year
PU	collection pick-ups per week
d	(aggregate) density of collected materials
sph	stops per hour made by truck
AUs	activity units per stop
G	tons of (targeted) waste generated
dv	diversion rate for (targeted) waste
dist	distance vehicle must drive to drop-off
mph	speed at which vehicle travels to drop-off
q	total vehicle queuing and unloading time

The variables used in this equation are values either entered into WastePlan or determined by WastePlan directly from input values and basic growth projections for population and/or waste generation. These input values were determined based on a combination of research and assumptions that will be herein described.

Loads per Day Equations

Note that the above two equations are linked by the following cascade of equations, which represents the internal logic employed by WastePlan to calculate truck loads per day. Input variables are italicized.

Loads per Day =

Integral Loads per Day + Fractional Loads per Day

Integral Loads per Day =

(the lowest integral value of:) *Collection Hours Per Day* / Total Time to Collect a Full Load

Total Time to Collect a Full Load =

Time to Collect One Load (on the street) + Time to Drop One Load

Time to Collect one Load (on the street) =

(*Compaction Ratio* x *Truck Capacity*) / Volume Collected per Hour

$$\text{Volume Collected per Hour} = \text{Stops per Hour} \times \text{Volume Collected per Stop}$$

$$\text{Volume Collected per Stop} = \text{Activity Units per Stop} \times \text{Volume per Set-Out per Activity Unit}$$

$$\text{Volume per Set-Out per Activity Unit} = \frac{\text{Total Volume per Pick-Up}}{\text{Number of Set-Outs}}$$

$$\text{Total Volume per Pick-Up} = \frac{\text{Total Annual Volume}}{\text{Total Pick-Ups per Year}}$$

$$\text{Total Annual Volume} = \text{Total Activity Units} \times \text{Tons per Activity Unit per Year} / \text{Density of Collected Material}$$

$$\text{Tons per Activity Unit per Year} = \frac{[\text{Total (targeted) Waste Generated} \times \text{Diversion Rate}]}{\text{Total Activity Units}}$$

$$\text{Total Pick-Ups per Year} = \text{Collections Weeks per Year} \times \text{Pick-ups per Week}$$

$$\text{Number of Set-Outs} = \text{Total Activity Units} \times \text{Set-Out Fraction} \times \text{Highest Participation Rate}$$

$$\text{Time to Drop one Load} = 2 \times (\text{Distance to Drop-Off} / \text{Vehicle MPH}) + \text{Vehicle Waiting and Unloading Time}$$

$$\text{Fractional Loads per Day} = \frac{\text{Remaining Fill Time following the Collection of One Load}}{\text{Time to Collect One Load (on the street)}}$$

$$\text{Remaining Fill Time Following the Collection of One Load} = \text{Collection Time Remaining} - \text{Time to Drop One Load}$$

$$\text{Collection Time Remaining} = \text{Collection Hours per Day} - (\text{Integral Loads per Day} \times \text{Total Time to Collect a Full Load})$$

Loads per Day Input Variables

This section will further describe those variables involved in the calculation of loads per day and discuss the specific methodology regarding how the values used in WastePlan were selected.

Total Collection Hours per Day. Based on conversations with OPEC, 4.75 hours was determined to be the hours available during a 7-hour shift for actual collection work. During this 4.75 hours crews collect waste at the curb and deliver it to either its drop-off destination or back to the garage, from which it is later relayed to its drop-off destination. The remaining time of the 7-hour

collection shift is spent either in meetings, on breaks, or at the garage in the performance of routine maintenance.³

The 4.75-hour collection time was increased an additional 30 minutes to 5.25 hours to account for the effect of relays, which operated at a 41% rate. To relay a vehicle means that the collection crew returns a full vehicle to the yard rather than to its drop-off destination and a second driver, working on a later shift, drives the full vehicle to its drop-off point. Relaying vehicles eliminates the time spent on route delivering a vehicle's content to its drop-off point, queuing in line and then returning to route. Thus, this practice effectively lengthens the hours available for collection for those vehicles that are relayed and dumped off-shift.

Because the WastePlan model does not account for relays but incorporates delivery, queuing, and return time into every collected load, an adjustment to this 4.75 hour collection time was necessary. The amount by which relays increases collection hours per day is equal to the average round-trip time (to drop-off point and back to the route) multiplied by the relay ratio. The average round-trip truck time was determined to average 65 minutes (see below sections on Vehicle Queuing and Unloading Time and Distance Vehicle Must Drive to Drop-Off); which, when multiplied by the 41% relay rate results in an increase of approximately 27 minutes.

According to the BCC, the container recycling program had an average trip time of 107 minutes and the paper recycling program had an average trip time of 135 minutes. Both had relay rates of 48%, resulting in an approximate average increase in the *recycling* collection day of 55 minutes. However, because the collection of solid waste is the overwhelming majority of truckshifts on the road, the 27 minute increase determined above was increased only slightly to 30 minutes per collection shift, creating an input value of 5.25 Total Collection Hours per Day.

All commercial collection programs were modeled over an eight hour day based on conversations with commercial haulers as reported in the GEIS appendices.⁴

Compaction Ratio of the Collection Vehicle. The following vehicles, with listed compaction ratios, were used in the final four scenarios modeled as part of the

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³ According to OPEC, crews will not return to their route after dropping a load if there is insufficient time to travel to route, collect waste, and then return to the garage within the 7-hour time period.

⁴ New York City Department of Sanitation. GEIS, Appendix 7-A.5 Initial Phase Scenarios -- Commercial Collection Memo #2: Methodology for Modeling Commercial Waste Management Programs, 1992.

New York City solid waste management planning process. Unless otherwise noted these vehicles were used in all four final scenarios.

- Automatic EZ Pak with a compaction ratio of 3:1 for all programs in which it is used
- Manual Rear Loader (used in the public sector in Scenarios A and D) with a compaction ratio of 4:1 when used for the collection of solid waste and 2.9:1 when used in Scenario A only for the collection of leaves and yardwaste
- Manual Dual-Compacting Rear Loader with a compaction ratio of 3:1 when used for the collection of recyclables in Scenarios A, B and C and 4:1 when used for compostables and solid waste in Scenarios B and C
- Manual Rear Loader (used in the commercial sector) with a compaction ratio of 5:1
- Front Loader Vehicle (used in the commercial sector) with a compaction ratio of 4:1
- Composite Base Case Vehicle with a compaction ratio of 4:1.

Devoid of specific information, a vehicle's rated capacity was assumed to be an accepted industry standard of 4:1. The derivation of the compaction ratios for each vehicle are described below.

Automatic EZ Pak Vehicle. Compaction for the EZ-Pak vehicle was taken to be 3:1 for all programs as indicated in Appendix 7-A.3, Table 7-A.3-1 of the Comprehensive Solid Waste Management Plan for New York City and Draft Generic Environmental Impact Statement.

Manual Rear Loader (Public). In the leaf and yardwaste collection program in Scenario A this truck has a compaction ratio of 2.9:1. This was based on data from both the generation and composition study conducted for New York,⁵ which indicated an average density for leaves of 230 lb/yd³ and a New York City Bureau of Waste Disposal pilot composting study⁶ that indicated a density of 667 lb/yd³ for collected leaves. Dividing the later figure by the former produces a compaction density of 2.9:1 for leaves. This value was maintained with the addition of other yardwaste to the program.

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⁵ SCS Engineers Inc. New York City Municipal Solid Waste Generation and Composition, 1991.

⁶ Martin Bellew and Michael Greenfield. Interim Report on Pilot Composting Project at Edgemere Landfill. New York City Department of Sanitation Bureau of Waste Disposal and Recycling Programs and Planning Division, April 5, 1990.

Manual Dual-Compacting Rear Loader. When used in recycling programs in Scenarios A, B, and C, this vehicle collects paper and related materials in one side and containers in the other side of the truck. Initially a conservative compaction ratio of 1.5:1 for paper and 2.5:1 for containers was assumed. However, when modeling this truck in the WastePlan model it is necessary to assign only one compaction value for the entire truck. Thus, the average of the above ratios -- 2:1 -- was the initial value used.

On-street testing of split-body compaction vehicles for recycling in New York City⁷ indicated that containers compacted at a 6:1 ratio and paper compacted at 2.5:1.⁸ This increased the average truck compaction ratio to 4:1, instead of the previously used 2:1. As a conservative estimate and compromise between the two values, the average compaction ratio was increased to 3:1. Some sources, such as Bill Davidson of the Northeast Maryland Disposal authority, indicate that compaction rates above 1.5:1 cause glass breakage and thus the DOS value may be too high. Nevertheless, the decision to use the New York City data was based in the fact that the information was primary data from DOS field studies.

Corroboration of this compaction ratio is found in a study of recycling collection alternatives presented to the New York City Department of Sanitation as part of the GEIS study and solid waste master plan.⁹ This study indicated that pilot blue bag collection programs targeting glass, metal and plastic containers only achieved satisfactory results with compaction ratios ranging from 2:1 to 3:1.¹⁰ Hennepin County, Minnesota was also successful using compaction ratios ranging from 2:1 to 3:1 for the collection of bagged, commingled recyclables.

Manual Rear Loader (Commercial). SCS Engineers, Inc. conducted a study of the vehicles used in New York City in both the public and

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⁷ New York City Department of Sanitation. GEIS Draft Appendix Volume 1.2, Waste Stream Data Compaction Study, 1992.

⁸ See R. Geller October 22, 1991 memo to DOS -- "Derivation of Theoretical Compaction Ratios".

⁹ New York City Department of Sanitation. Appendix Volume 4.1, Waste Management Components, Collection: Detailed Analysis, 1992.

¹⁰ Glass breakage in this program was reported to be in the range of 5%.

private sectors.¹¹ They concluded that vehicles in the private sector achieved a higher level of compaction than those in the public sector for two main reasons:

- The quality of the waste collected
- A higher set compaction rate coupled with more attention to vehicle maintenance.

A higher percentage of commercial waste consists of highly compactable corrugated containers (projected to be approximately 20% in 2000) than is found in the residential sector (approximately 5% in 2000). Plastic films and bags also are projected to occupy a high percentage by volume in the commercial sector (approximately 17% in 2000).¹² This consideration suggested the use of a compaction ratio greater than the standard 4:1.

Self-reporting by commercial haulers also indicated their belief that they achieved a compaction ratio of 5:1, which is the value used in modeling the four collection scenarios.

Useable Vehicle Capacity. The useable capacities of the vehicles used to model collection programs for New York City are as follows:

- Automatic EZ Pak with a capacity of 47yd³
- Manual Rear Loader (used in the public sector) with a capacity of 25yd³
- Manual Dual-Compacting Rear Loader with a useable capacity of 18.75yd³
- Manual Rear Loader (used in the commercial sector) with a capacity of 31yd³
- Front Loader Vehicle (used in the commercial sector) with a capacity of 40yd³
- Composite Base Case Vehicle with a capacity of 23.97yd³.

The useable capacities of all vehicles other than the Composite Base Case Vehicle and the Manual Dual-Compacting Rear Loader are simply the vehicle's rated capacity. In other words, it was assumed those vehicles would make use of all available volume in the collection of waste, compostables, and recyclables.

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¹¹ New York City Department of Sanitation. GEIS, Appendix Volume 4.1: Waste Management Components, 1992.

¹² New York City Department of Sanitation. GEIS, Appendix Volume 7-A.2, Waste Stream Characteristics, 1992.

Only for the dual-compacting vehicle, used for collecting recyclables in Scenarios A, B, and C and waste in Scenarios B and C, was the useable capacity different from the rated capacity. The capacity of the Composite Base Case Vehicle represents a weighted average of the capacities of vehicles used in the 59 sanitation districts in 1990. The determination of these values will be fully described in the following paragraphs.

Manual Dual-Compacting Rear Loader. This truck has a maximum capacity of 25-yd³ divided between two independently compacting containers. When used in the recycling programs in Scenarios A, B, and C, one side of the truck is used for collecting paper and the other side for collecting containers; when used for refuse and organics collection in Scenarios B and C, one side of the truck is used for compostable waste and the other side for dry waste. These dual-compacting sides can be set to any desired proportional split, i.e., the truck can be set to accommodate a 3:2 volume split and it is not limited to a 1:1 split.

Determining the proper volume split between the two sides of the recycling compactor was based on our analysis that the *uncompacted* volume split between targeted paper and containers ranged from between 36/64 and 39/61 depending on the targeted sector. Assuming a conservative compaction ratio of 1.5:1 for paper and 2.5:1 for containers, for an average compaction ratio of 2:1, created a volume split of roughly 25/75 to 28/72 for the collection of recyclables, depending on the targeted sector.

As previously mentioned, the compaction ratio for the recycling programs was set to 3:1. This had the effect of changing the volume split between the container and paper sides of the recycling vehicle as the ratio of the compacted volumes for these materials now ranged from 38/62 to 40/60.

An analysis of the volume split for the collection of organics and remaining solid waste indicated an uncompacted volume ratio ranging from 23/77 to 28/72. We assumed that there would not be any differential compaction between these two sides yielding an average volume split of 25/75 between the two sides of the truck.

When using a split-body truck, because one side of the truck will almost always fill before the other side, it is necessary to assume less than 100% utilization of available truck volume. This results from the fact that the filling of one side necessitates a trip to the truck's

drop-off destination, meaning that some proportion of the truck's rated capacity will always go unused.

To estimate the proportion of unused capacity, a conservative estimate of a 40/60 volume split was made for both the recycling and solid waste/organics vehicles, with the 40% side collecting paper or organics and the 60% side used for containers or remaining solid waste. A second conservative assumption was made -- that half of one side of the truck would be empty when the other half was full. If half of the paper/solid waste side of the truck were not utilized, effectively 20% of the truck volume would be lost; if half of the containers/organics side of the truck were not utilized 30% of the truck volume would not be used. The average of these two -- 25% -- was used in all subsequent modeling of collection using the dual-compacting vehicle. This meant the usable volume of the truck was 18.75yd³.

Composite Base Case Vehicle. The Composite Base Case Vehicle is a vehicle created for the Base Case analysis as a simplifying step in describing city-wide collection programs as they existed in 1990. This vehicle's volume is a weighted average of the truck fleet employed by New York City to collect residential and institutional waste from the city's 59 sanitation districts. In 1990 34 districts used 25yd³ rear-loading packer trucks, 15 districts used 20yd³ rear packers and ten districts used 25yd³ side-loading packer trucks, producing a weighted average of 23.97yd³.¹³

This composite vehicle was used to model collection of recyclables, compostables and solid waste from the institutional sector in the initial and final analyses of the solid waste master plan. It was used in all four final scenarios. It was not used in the residential sector because residential collection lent itself to more detailed analysis than in the institutional sector. Its use reduced the complexity of modeling waste collection from the eight subsectors that comprised the institutional sector. In 1990 institutional waste was collected by four different types of vehicles: rear- and side-loading packer trucks, hoist-fitted chassis trucks, roll-on roll-off trucks, and automated EZ-PAK trucks. Generally, the information about institutional collection was much less complete than was information about residential collection for the following reasons:

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¹³ Bureau of Cleaning and Collection. Sequential Order on Monitor Program, BCC 7A/(DS 290 A Revised).

- Institutions, unlike residences, are not evenly spaced throughout the city making it difficult to develop accurate information about collection efficiency
- Not all institutions received collection service from the city, pushing some of the institutional waste into the commercial sector
- Institutional waste was commingled with residential waste indicating that neither trucks nor routes were wholly dedicated to the collection of institutional waste.

These factors combined to force arbitrary but informed assumptions to assign the four types of existing vehicles to each of the eight institutional subsectors. This was performed and documented in the development of a city-wide institutional baseline describing waste collection from the institutional sector in 1990.¹⁴

Another factor influencing the decision to model an institutional collection vehicle was the uncertainty regarding the location of institutional waste generation. The distribution of institutional solid waste among the city's five boroughs was already pushing the limits of available data regarding the location of city institutions; further abstraction to the level of the 59 sanitation districts would have served no purpose other than to further obscure the city-wide distribution of institutions. It was decided that no useful purpose would be served by modeling a projected multiple vehicle institutional collection fleet to collect waste whose point of origin was uncertain. Any information gained through detailed modeling of vehicles would have been obscured due to uncertainties about point of waste generation.

In addition, institutional waste is projected to account for approximately 11% of the municipal solid waste generated in New York City by year 2000. So, rather than maintain the complex model structure created in the institutional baseline for the collection of institutional recyclables, solid waste, and the new collection of organics, especially for a relatively small portion of the waste stream, it was decided to use collection programs and a collection vehicle that could serve as proxy for the four types of

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¹⁴ See "New York City's Baseline Solid Waste and Recycling Collection Program Evaluation; Institutional Curbside and Containerized Collections for Fiscal Year 1990," in New York City Department of Sanitation, GEIS, Appendix 4-0: Baseline Analysis of Collection/Processing/Disposal Systems, 1992.

vehicles actually operating in 1990. The Composite Base Case Vehicle, because it represented a weighted average of curbside vehicles used by DOS throughout the city, was the selected vehicle.

Manual Rear Loaders. In 1990, the Department of Sanitation used a fleet of 20yd³ and 25yd³ vehicles while the rear loader of choice for the private sector was a 31yd³ vehicle. This difference in capacities reflected the need of department vehicles to navigate narrow streets with tight turns along mostly residential routes, whereas the private vehicles, following commercial routes and able to avoid residential areas, were able to realize the economies of scale associated with the larger capacity vehicles.

That a 25yd³ vehicle was chosen as the public collection vehicle in the solid waste master plan instead of a vehicle with a weighted average capacity intermediate between 25yd³ and 20yd³ reflected the Department of Sanitation's stated desire to gradually phase out use of the smaller vehicle.¹⁵

Total Activity Units Targeted. This is simply the number of generating units to which a particular program is targeted. In the residential sector in New York City it is equal to the total number of households in a sanitation district (as each collection program was created specifically for one district only). This information was derived from household data from each community district (in the Community District Needs Books¹⁶) and projections of household growth as determined in the population forecast conducted as part of the solid waste planning study.¹⁷

Activity units in the institutional and commercial sectors ranged from beds (in the hospitals) to students (in the schools) to employees (in most other sectors).

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¹⁵ Telephone communication between R. Geller and Mitchell Zaretsky from Operations Planning Evaluation and Control, Department of Sanitation, June 1991.

¹⁶ Department of City Planning, Office of Management and Budget. Community District Needs Fiscal Year 1991, October 1989.

Department of City Planning, Office of Management and Budget. Community District Facts-At-A-Glance, for each of 59 Community Districts, 1990.

¹⁷ John Stutz and Gary Prince. Statistical Profile of New York City for Solid Waste Management Planning, Tellus Institute, 1991.

Number of units in these sectors was determined and projected to grow as reported in the forecast study.¹⁸

Set-Out Rate for Targeted Materials. The set-out rate is the frequency at which program participants put their containers to the curb for collection. This variable determines the number of stops a collection vehicle will make along its route. A simplifying assumption of a 100% set-out rate was made to ensure that a collection vehicle would stop at all participating homes (and businesses and institutions) in every program. Two principal factors contributed to this decision, as follows:

- The nature of New York City residences, with few single-family structures in many locations, ensures a high probability that at least one program participant would set material out at the curb
- Small residences and a slightly reduced collection schedule in many areas would tend to encourage use of all available collection opportunities (see below section on "Collection Pick-Ups per Week" for a discussion of reduced collection schedules).

Highest Participation Rate. The highest participation rate in all refuse collection programs is always 100% reflecting the fact that whatever remains in the waste stream following prevention, recycling, and composting collection programs must be collected as refuse. It is in the recycling and composting collection programs that participation is generally less than 100%. Participation rates are assigned on a per-material basis; the highest rate is significant because it helps define the population requiring collection service. For example, in a targeted sector 85% of residents may recycle their newspapers whereas only 65% will recycle their steel cans. Because set-out materials must always be collected, collection vehicles will stop at 85% of all possible stops, even though they will only find steel cans at little more than half of those stops.

See the discussion below under Diversion Rate for (Targeted) Waste for a discussion of the derivation of participation rates.

Collection Weeks per Year. Materials are collected all 52 weeks of the year.

Collection Pick-Ups per Week. This variable represents the number of times in a week that residents are offered collection service. This value ranged from two to

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¹⁸ John Stutz and Gary Prince. Statistical Profile of New York City for Solid Waste Management Planning, Tellus Institute, 1991.

five times per week in 1990, depending on the sanitation district,¹⁹ and the following methodology was employed to create weighted averages specific to each of the four housing densities found in the city:

- Collection pick-ups per week in each district were multiplied by the number of households of each residential density type within that district
- For each density type the sum of these products was then divided by the total number of households of each density type to produce city-wide averages by density type.

This produced a weighted average of pick-ups per week for curbside residential refuse collection in each density sector.²⁰ Curbside recycling collection was always once per week where such programs existed.

These values informed the next step of the process in which it was assumed that the development of extensive recycling and source reduction programs throughout the city the frequency with which solid waste needed to be collected would decrease. While recycling programs were maintained at one pick-up per week, solid waste (and combined solid waste/organic) collection programs were reduced in frequency to reflect the decreased tonnage disposed of, and therefore the decreased need to have containers emptied as frequently. Low-density neighborhoods were assigned one pick-up per week, middle-density and high-density neighborhoods were assigned two and three pick-ups per week, respectively. District-specific values were then created by multiplying the proportion of households of each density type in each sanitation district by the collections per week assumed for each level of residential density.

Commercial collections occurred an average of three times per week based on conversations with commercial haulers in New York City, and were modeled as such in developing the City's solid waste master plan. This was also the number used for the collection of institutional waste.

(Aggregate) Density of Collected Materials. The aggregate density of materials collected by any one program is calculated by WastePlan based on the tons collected and the density of each material type as determined in the generation

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¹⁹ New York City Department of Sanitation, Bureau of Cleaning and Collection. Districts Sections Frequency Report, revised 1/17/89.

²⁰ See the "Baseline Analysis of Collection/Processing/Disposal Systems" in GEIS Appendix 4-0. See also New York City Department of Sanitation, GEIS, Appendix 7-A.5: Initial Phase Scenarios -- Collection Methodology Memo #1: Methodology for Deriving Collection Efficiency and Diversion Rate on a District-Specific Basis, 1992.

and composition study conducted for the Department of Sanitation by SCS Engineers, Inc.²¹ The tons of materials collected is calculated as the product of:

tons available in the wastestream x participation rate
in the program x capture rate for each material.

Stops per Hour Made by Truck. Stops per hour is defined as the number of stops a collection vehicle makes per hour to pick-up materials set out for collection. This figure pertains only to those hours when the vehicle is actually collecting and does not include the time spent by the vehicle driving to its drop-off destination. All residential collection programs made use of stops per hour in determining the efficiency of collection. Stop per hour information for all residential programs was specific to the sanitation district in which the program operated and was generated from data developed in the determination of baseline conditions in the city in 1990.

In determining baseline collection efficiencies all the essential outputs and most of the essential inputs were known. The method for determining both recycling and refuse stops per hour was to assign different values, by trial and error, until the model produced the correct known values. By way of explanation, the number of tons collected from each density sector was known, as was the number of truck shifts operating in each density sector. The methodology employed simply required entering values for stops per hour in the collection algorithm to collect the correct tons of material until the actual number of existing truck shifts was replicated. This method assumed that we had the correct values for many other variables, such as collection hours per day, pick-ups per week, etc.²²

This methodology provided density-specific stops per hour for the baseline refuse and recycling collection programs. Stops per hour for each of the 59 sanitation districts in Scenarios A, B, C and D were then assigned by weighting the density-specific stops per hour by the proportion of each residential housing density found in a district.²³

The stops per hour variable, in conjunction with other variables that provide information about collected volume per stop, is one method employed by

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²¹ SCS Engineers, Inc. New York City Municipal Solid Waste Generation and Composition, 1991.

²² See New York City Department of Sanitation. GEIS, Appendix 4-0: Baseline Analysis of Collection/Processing/Disposal Systems, 1992.

²³ See R. Geller memo to DOS, "Sanitation District Collection Efficiencies: Compromises," July 26, 1991.

WastePlan to calculate tons collected per truck shift. A second method, and that employed for the collection of commercial and institutional waste, was assigning a value for overall collected tons per hour by a vehicle when it is on route. This alternate method is preferable when the stops on the route are widely dispersed as found in commercial and institutional sectors. Stops per hour is viable only when the stops are located in close proximity to one another as in a residential sector.

Tons collected per hour in the institutional sector was determined to range from 2.2 to 9.9, depending on type of vehicle employed. Values ranged from 2.2 to 2.9 tons per hour for the 23.97yd³ Composite Base Case Vehicle, and up to 3.6 tons per hour for the 47yd³ Automatic EZ Pak vehicle. These latter figures were more relevant as they better represent the types of vehicles modeled in the institutional and commercial sectors. Because the data on institutional collection was relatively "soft,"²⁴ it was decided to assign the value of three tons of waste collected per hour from the institutional sector. Since there was even less information available about commercial collection efficiencies, and due to the shared characteristics of the two programs (i.e., non-contiguous stops) this value was also applied to the commercial sector.²⁵

Activity Units per Stop. Activity units are defined as the waste-generating unit in any collection program. Typical waste generators or activity units are individuals and households. Residential activity units in the New York City solid waste master plan were defined as households.

The first step in determining activity units, or households, per stop is the determination of the total number of households in New York City per sanitation district. This information is readily available from the city's Community District Needs Books, which has specific housing information for each community

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²⁴ Some of the problems with the institutional collection data were:

- Few vehicles were specifically assigned to the collection of institutional waste -- the collection of institutional waste was generally incorporated into residential routes, thus requiring assumptions about tonnage distribution to arrive at total institutional truckshifts
- A lack of information about the distribution of tons generated between the eight subsectors comprising the institutional sector
- Some of the institutional subsectors were serviced by both the DOS and commercial haulers.

²⁵ See New York City Department of Sanitation. GEIS, New York City's Baseline Solid Waste and Recycling Collection Program Evaluation: Institutional Curbside and Containerized Collections for Fiscal Year 1990, 1992.

district.²⁶ This data, which dated from 1988, was adjusted to agree with forecasted growth in each borough.²⁷ Once the total number of households was determined they were assigned to the low- medium- and high-density sectors based on the proportion of that housing stock in each sanitation district as reported by OPEC.²⁸

Households in the high-density sector had to be further divided between those receiving curbside collection service and those receiving containerized collection service. This division was accomplished by dividing the number of containerized tons originating from each district by the high-density waste generation rate to arrive at the number of households receiving containerized collection service.

Once households per density sector for each sanitation district was determined, the next step was the determination of households per stop. That was accomplished for each density sector as follows:

Low-Density. The definition of low-density households are those in buildings with 1-4 units. The Community District Needs Books list, by district, the number of 1-2 family buildings. For each district it is also known, as described above, the total number of low-density households. Using this information, an average value for the number of low-density stops per district was determined as follows:

1. Determine the average number of stops at 1-2 family households assuming an equal split between 1 and 2 family buildings
2. Determine the average number of stops at 3-4 family households, again assuming an equal split between 3 and 4 family buildings²⁹

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²⁶ Community districts are coterminous with sanitation districts.

²⁷ See New York City Department of Sanitation. GEIS, Appendix 4.0: Baseline Analysis of Collection/Processing/Disposal Systems -- New York City's Baseline Solid Waste and Recycling Collection Program Evaluation: Residential Curbside and Containerized Collections for Fiscal Year 1990 -- Table D, 1992.

²⁸ See 2/13/91 memo from Edward Leibnitz, Staff Analyst, DOS OPEC to R. Geller.

²⁹ This was done by subtracting from the total number of low-density households those projected to be in 1-2 family buildings. This remaining total number of households was used to determine the number of buildings with 3 and 4 units by assuming half the remaining households were in 3-unit buildings and half were in 4-unit buildings.

3. Sum the total number of low-density stops from (1) and (2) and divide into the total number of low-density households per district.

The city-wide low-density households per stop were taken as a weighted average of the households per stop in each district; the weighting factor was the number of low-density households in each district.

Medium-Density. This was assumed to be five households per stop. Given the above determination for low-density households per stop, there were still more than two unknowns in essentially one equation. One sector had to be assigned a value for its activity units per stop. The medium-density sector was chosen because it was the smallest sector. Five activity units per stop was the value recommended by SCS Engineers, Inc. in their survey of city collection programs.

High-Density, Containerized. There are two containerized sectors in New York City. The primary containerized sector consists of those households with containerized refuse collection service. The other containerized sector consists of those buildings not containerized for refuse but which receive containerized recycling service. The primary containerized high-density sector consists of 143,382 households out of a total of 1,745,414 high-density households. Of those, according to a document from the DOS Office of Recycling,³⁰ more than 100,000 households participate in containerized paper recycling. Based on data about those households participating in the city's containerized recycling programs, the Office of Recycling determined: the number of sites with containerized recycling, buildings at these sites, and units in these buildings. According to the Office of Recycling, "there are multiple buildings on many sites, there are sometimes multiple stops per site. However, there are not as many stops per site as buildings." The important information to determine is how many stops per site there are for containerized collection. The recycling office estimated that there were 1.3 stops per site in Manhattan and 3 stops per site in the other boroughs. Using this assumption, it was calculated that there are 279 households per stop in buildings both containerized for recycling and solid waste, and 198 households per stop in buildings containerized for recycling but not for solid waste.

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³⁰ Memorandum from Pat Grayson, Office of Recycling to Jim Meyer, Office of Resource Recovery, October 30, 1990, "Containerized Recycling Sites Throughout the Five Boroughs."

These figures take into account only those buildings receiving containerized recycling service in fiscal year 1990.³¹

The figure of 279 households per stop was applied to all households in the primary containerized sector as the information about recycling in this sector represented the majority of households in the sector.

High-Density, Curbside. Households per stop at the remainder of the high-density sector was determined by dividing the high-density households in each district that receive curbside solid waste collection by the remaining number of stops in each district after accounting for those in the low, medium, and containerized sectors. As with all household-per-stop numbers (except for that of the medium-density sector, which was chosen), the city-wide average represents a weighted average of the value for each sanitation district.

The above methodology produced city-wide average for each housing density sector; these numbers were then used to create district-specific activity units per stop by weighting the city-wide numbers by the proportion in each district of low-, medium-, and high-density households.

Tons of (Targeted) Waste Generated. The generation of residential, institutional, and commercial waste in 1990 was based on the generation and composition study conducted by SCS Engineers for the Department of Sanitation as part of the GEIS process. The Tellus Institute then performed an analysis to forecast the projected growth of waste generating units and waste generation rates, and changes in the relative composition of waste over the 20-year period beginning in 1990. This information formed the foundation of projected waste generation throughout the planning period.³²

Since not all wastes are targeted in a source separation program, only tonnages of those wastes targeted for collection by any one program are significant in the determination of loads per day.

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³¹ Memorandum from Linda Ostreicher, Office of Recycling, to Marcia Bystry, March 19, 1991, re: "Number of Stops per Unit in Containerized Buildings."

³² John Stutz and Gary Prince. Statistical Profile of New York City for Solid Waste Management Planning, Tellus Institute, 1991.

SCS Engineers, Inc. New York City Municipal Solid Waste Generation and Composition, 1991.

Diversion Rate for (Targeted) Waste. The diversion rate for any one material is the product of participation and capture rates for that material as it is targeted in a collection program. Participation rate is simply that fraction of activity units (i.e., households) who participate in the program by separating the targeted material for collection. Capture rate represents the fraction of the material generated by participants they actually set out for collection. Since the diversion rates for refuse collection is always 100% of any waste remaining following prevention and source separation programs, it is the derivation of these later rates with which this section is concerned.

Recycling diversion rates were calculated from baseline conditions in New York City in 1990. This calculation was based on data in the city's generation and composition study, which revealed the total amount of potentially recyclable materials in the residential sector, and data from DOS about tons of recyclable materials collected. From this information it was possible to calculate diversion rates for each residential density sector. Because diversion rates are the product of two other variables, one of the variables had to be assumed. An assumption was made about capture rates, and from this participation rates could be derived.³³

As with many of the other variables used in this study, participation and capture rates were created specifically for each sanitation district by weighting the density-specific values by the proportion of each density category found in the districts. These existing rates were applied to the first year of collection programs in each scenario. The rates were then increased annually until they reached a plateau in the year 2000 that was approximately 10-20 percentage points higher than the initial values.

Because residential organics collection always occurred in conjunction with refuse collection, organics diversion rates are irrelevant to the purposes of this study.

Capture and participation rates for the commercial and institutional sectors were also grown to a plateau in year 2000. Initial rates were chosen to reflect the minimal level of commercial and institutional recycling in New York in 1990; plateau levels were chosen to help achieve the mandated 40% diversion of materials from the waste stream.³⁴

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³³ See New York City Department of Sanitation. GEIS, Appendix 4-0: Baseline Analysis of Collection/Processing/Disposal Systems, 1992.

³⁴ New York City Department of Sanitation. GEIS, Appendix 7-A.5 Initial Phase Scenarios Commercial Collection Memo #2: Methodology for Modeling Commercial Waste Management Programs, 1992.

Distance Vehicle Must Drive to Drop-Off. In the final stage of the New York City solid waste management planning process collected waste from every residential, commercial and institutional program was routed to a specific (projected) facility. In the many cases when these facilities were not yet in existence they were sited at projected locations on a New York City map, based on the siting analysis conducted as part of the New York City Solid Waste Management Master Plan and Generic Environmental Impact Analysis.³⁵

Distances from the center of each sanitation district or sanitation zone were then measured to create theoretical distances to destinations for every program and district. However, for a significant proportion of the districts travel distances were known. A comparison of the measured distance to the actual distance for those districts revealed a 16.5% error in the theoretical distances. This percentage was then used as a correction factor for all other theoretical distances. In this way program- and district-specific distances to drop-off points were created for every vehicle.³⁶

Speed at which Vehicle Travels to Drop-Off. Miles per hour travelled by collection vehicles were created in one of two ways: they were either created on a district-specific basis, or were assigned a value of 12 miles per hour. District-specific miles per hour were calculated for those districts about which both actual distance to drop-off and minutes of travel time were known. The assignment of a default vehicle speed in lieu of other information was based on conversations with DOS Bureau of Cleaning and Collection staff.³⁷

Total Vehicle Queuing and Unloading Time. Vehicle queuing and unloading times includes all time a vehicle spends waiting to enter the yard of its drop-off destination, dumping collected materials, and then leaving the yard on its way back to either its collection route or garage. This time was set as 25 minutes for all refuse collection programs and 5 minutes for all recycling collection programs. These values were assumed in the absence of any data. Times for the recycling programs was assumed to be significantly shorter as it was not expected that they would experience the same level of queuing as for trucks arriving at transfer stations.

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³⁵ Tellus. NYC GEIS Siting Study, 1992.

³⁶ New York City Department of Sanitation. GEIS, Appendix 7-A.5 Initial Phase Scenarios, Collection Methodology Memo #1: Methodology for Deriving Collection Efficiency and Diversion Rates on a District-Specific Basis, 1992.

³⁷ New York City Department of Sanitation. GEIS, Appendix 4-0: Baseline Analysis of Collection/Processing/Disposal Systems, 1992.

COLLECTION VARIABLES: DEFINING TRUCKS NEEDED PER DAY

The variable Trucks Needed per Collection Day, like Truck Loads per Day, is a dependent variable. The number of trucks required to collect the targeted waste associated with any collection program is calculated by the WastePlan computer model using input variables derived from raw data.

Like Loads per Day, the equation for Trucks Needed per Day is simple in form -- it is simply the quotient of the total volume collected in a day by the total volume held by a truck in a day. The equation representing this is:

$$TPD = V_c \div V_d$$

where TPD represents Trucks Needed per Collection Day, and V_c and V_d represent Volume per Collection Day and Volume Held per Truck per Day, respectively. However, neither V_c nor V_d are input values. When the above equation is broken down into its constituent input values we have the following equation:

$$TPD = \frac{G \times dv}{LPD \times d \times w \times C \times cr \times D}$$

All but one variable used in this equation is defined in the previous section Loads per Day Input Variables. The only new variable, D , represents the number of collection days per week. Collection days per week is defined as the number of days in a seven day week that collection vehicles are on the road collecting targeted materials from a targeted sector. New York City collects materials 302 days per year; over a 52-week year this averages to 5.81 collection days per week, which was the value used in developing the City's solid waste management plan.

LPD in this equation represents Loads per Day as defined and described in the preceding section.

Trucks Needed per Collection Day Equations

The following equations demonstrate the logic of the trucks per day algorithm in showing the cascade of equations leading to original, input variables. All input variables are italicized.

$$\text{Trucks Needed per Collection Day} = \frac{\text{Volume per Collection Day}}{\text{Total Volume Held per Truck per Day}}$$

Volume per Collection Day =

Total Annual (Targeted) Volume/Collection Days per Year

Total Annual (Targeted) Volume =

Total Activity Units Targeted x Tons per Activity Unit per Year/(Aggregate) Density of Collected Materials

Tons per Activity Unit per Year =

[Total (targeted) Waste Generated x Diversion Rate]/Total Activity Units Targeted

Collection Days per Year =

Collection Weeks per Year x Collection Days per Week

Total Volume Held per Truck per Day =

Loads per Day x Truck Capacity x Compaction Ratio

DERIVATION OF FUEL EFFICIENCY

The remaining significant variable in the calculation of fuel use is that relating to the fuel efficiency of the vehicles used in collection programs. SCS Engineers, Inc. conducted a study of fuel use by collection vehicles employed by the Department of Sanitation in 1990. They concluded that the collection vehicles, on average, consume 4 gallons of fuel per hour of operation. However, a second look at the data indicates that fuel efficiency by the city's existing fleet of collection vehicles may be significantly better than that.

Information sent to the Tellus Institute from the Department of Sanitation in August of 1991 indicated that the DOS Office of Management and Budget (OMB) reported a total expenditure of \$1,844,571 for the purchase of fuel for the DOS solid waste collection fleet. A separate memo from SCS Engineers to the Department of Sanitation indicated an average diesel fuel price of \$0.93 per gallon in New York City in 1990. The quotient of these two numbers indicates theoretical fuel use of 1,985,545 gallons.

It is also known that the city operated a total of 1,190 daily truck shifts for the collection of all waste. Assuming the average hours per working day is 5.25, as discussed above, then over the 302 working days per year the DOS collection fleet consumed approximately 1.05 gallons of fuel per hour of vehicle operation.

When this figure for fuel efficiency is used to calculate miles per gallon, in conjunction with a theoretical value of miles travelled per vehicle per collection shift, the resulting values range from 2.6 to 8.0 miles per gallon depending on vehicle and collection program. The average of these calculated values is 4.7 miles per gallon. This figure is in better agreement with information provided by

truck manufacturers, who state their packer trucks achieve fuel efficiency values between 6 to 8 miles per gallon.³⁸

Thus, lacking better information about a difficult to arrive at number, the value of 1 gallon per hour of vehicle operation was utilized.

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³⁸ Some of those numbers are based on highway conditions where fuel efficiency will be significantly better than on a collection route.

APPENDIX II-B

DESCRIBING THE TRANSFER ANALYSIS

APPENDIX II-B

DESCRIBING THE TRANSFER MILEAGE ANALYSIS IN THE NEW YORK CITY GEIS PLANNING PROCESS

The transfer of materials between processing and disposal systems is inherent in any solid waste management system. Recycling and composting facilities produce residue that must be disposed, and collection vehicles deliver their loads to transfer stations, rather than directly to disposal facilities. Finally, municipal waste combustors must transfer ash to landfill sites.

The preparation of a generic environmental impact statement necessitated considering the effect of increased traffic associated with the solid waste management plan on New York City's urban environment. This transfer of materials between facilities was one source of increased traffic requiring analysis in each of the four final scenarios.¹

CONDUCTING THE TRANSFER ANALYSIS

Two types of transport were considered in this analysis: truck traffic for transport of materials on land between two facilities, and barge traffic for the transport of material on New York's waterways. A detailed analysis was conducted for two of the four scenarios -- B and D -- that took into account tons of waste transferred from each facility, destination facility, and distance from one facility to another as measured on a map. For those facilities not in existence in 1990, proposed locations were taken as proxy for actual facility locations.

Total annual transfer miles was calculated using the following equations:

$$\text{Total Annual Transfer Miles} = \text{Loads/Year} \times \text{Round Trip Miles}$$

$$\text{Loads/Year} = \text{Tons/Year} \div 20 \text{ Tons/Load (1,950 Tons/Load for a barge)}$$

As noted above, round trip miles were measured as facility-to-facility distances from a New York City map.

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¹ The other sources of vehicle miles considered in this analysis were miles travelled by collection vehicles, and average daily vehicle traffic by employees of the facilities.

From the information about these two scenarios transfer vehicle miles were developed for the other two final scenarios -- A and C. This simplifying step was performed for one main reason: the difference in transfer vehicle miles between scenarios B and D is relatively small (approximately 500,000 miles) in comparison to total vehicle miles travelled when collection programs were considered in the analysis. The simplifying step involved calculating transfer miles by vehicle type based on total tons in those scenarios to be transferred by either truck or barge.

This analysis hinged on information from WastePlan outputs and several assumptions. First, known about each scenario were: tons transferred by each facility, the days of operation at each facility, and the facility to which materials were being transferred². The analysis of vehicle miles traveled then hinges on several assumptions, the most noteworthy of which was that each truck load was assumed to weigh 20 tons and each full barge load was assumed to weigh 1,950 tons³. Based on this information and assumptions the number of loads per year was determined.

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² In some cases the facilities to which materials are transferred as reported in this memo differ from that reported in WastePlan. This is true especially in the cases where residue from MRFs, for example, is sent directly to the landfill in WastePlan. In reality, processing residue eventually bound for the landfill will first pass through a marine transfer station. In this analysis, residue that would in reality be sent to a transfer station is sent to the landfill through the most proximate marine transfer station in order to correctly model transfer miles. This was not modeled in WastePlan because of the model's limitations in dealing with multiple diversion streams from one facility.

³ See Memo from R. Geller to New York City, Department of Sanitation, "Transfer Miles; Final Scenarios and Base Cases," January 3, 1992.

Table II-B.1. Transfer Vehicle Miles, Scenario B.

Transferred From	Tons/Year ¹	Volume/Year	Tons Transferred per Day ²	Loads/Day	Round Trip Miles/Load	Total Annual Transfer Miles	Transferred To	By
Manhattan MRF	22,712	45,424	75	4	12	13,627	West 59th St. MTS	40 cy roll-off truck
Bronx MRF	24,795	49,590	82	4	9	11,158	West 135th St. MTS	40 cy roll-off truck
Brooklyn MRF	26,245	52,489	87	4	12	15,747	Greenpoint MRF	40 cy roll-off truck
South Queens MRF	24,292	48,584	80	4	24	29,150	North Shore MTS	40 cy roll-off truck
North Queens MRF	22,551	45,103	75	4	1	1,128	North Shore MTS	40 cy roll-off truck
Staten Island MRF	23,294	46,588	77	4	8	9,318	MSW Landfill	40 cy roll-off truck
West 135th St. MTS	340,560	941,713	1,128	0.58	50	8,732	Brooklyn Navy Yard Incinerator	Barge
West 135th St. MTS (org)	92,307	151,950	306	0.16	36	1,704	Staten Island Invesel Compost	Barge
East 91st St. MTS	128,304	454,889	425	0.22	46	3,027	Brooklyn Navy Yard Incinerator	Barge
East 91st St. MTS (org)	44,727	83,002	148	0.08	32	734	Staten Island Invesel Compost	Barge
West 59th St. MTS	118,910	406,808	394	0.20	42	2,561	Brooklyn Navy Yard Incinerator	Barge
West 59th St. MTS (org)	39,952	73,403	132	0.07	30	615	Staten Island Invesel Compost	Barge
West 59th St. MTS (commercial org)	332,439	450,287	1,101	0.56	52	8,865	Jamaica Bay Invesel Compost	Barge
Greenpoint MTS	353,749	854,249	1,171	0.60	43	7,801	Staten Island 3000 TPD WTE	Barge
Greenpoint MTS (org)	172,650	309,461	572	0.29	43	3,807	Staten Island Invesel Compost	Barge
SW Brooklyn MTS (org)	121,899	218,656	404	0.21	32	2,000	Staten Island Invesel Compost	Barge
Brooklyn Navy Yard Incinerator ³	169,231	328,923	464	0.24	36	3,124	Ash Landfill	Barge
Bronx 1500 TPD WTE	45,081	87,621	124	6	70	157,784	Ash Landfill	40 cy roll-off truck
Staten Island 3000 TPD WTE	112,955	219,543	309	15	8	45,182	Ash Landfill	40 cy roll-off truck
Spring Creek WTE 1500 TPD	54,396	105,726	149	7	52	141,430	Ash Landfill	40 cy roll-off truck
Greenpoint Incinerator ⁴	36,022	70,014	99	0.05	43	794	Ash Landfill	Barge
Southwest Incinerator	35,638	69,267	98	0.05	32	585	Ash Landfill	Barge
Betts Avenue Incinerator	37,377	72,647	102	5	45	84,098	Ash Landfill	40 cy roll-off truck
Commercial Paper Processing	284,112	568,224	941	47	4	56,822	Closest MTS	40 cy roll-off truck
Commercial High Quality MRFS	72,323	144,645	239	12	4	14,465	Closest MTS	40 cy roll-off truck
S. Bronx Invesel Compost 470 TPD	10,713	21,426	29	1	10	5,357	West 135th St. MTS	40 cy roll-off truck
N. Queens Invesel Compost 600 TPD	13,588	27,176	37	2	1	679	North Shore MTS	40 cy roll-off truck
Jamaica Bay Invesel Compost 1500 TPD	23,271	46,542	64	3	36	41,888	Southwest Brooklyn MTS	40 cy roll-off truck
Staten Island Invesel Compost 1500 TPD	37,295	74,591	102	5	8	14,918	MSW Landfill	40 cy roll-off truck
West 59th St. MTS (commercial to SI)	520,343	1,322,984	1,723	0.88	30	8,005	Staten Island 3000 TPD WTE	Barge
SW Commercial Waste Processing	22,990	61,657	76	4	4	4,598	Southwest Incinerator	40 cy roll-off truck
Betts Commercial Waste Processing	79,937	202,197	265	13	4	15,987	Betts Avenue Incinerator	40 cy roll-off truck
Brklyn Navy Yard Comm. Waste Processing	377,651	951,740	1,251	63	4	75,530	Brooklyn Navy Yard Incinerator	40 cy roll-off truck
NW Bronx Commercial Waste Processing	202,231	455,120	670	33	4	40,446	Bronx 1500 TPD WTE	40 cy roll-off truck
SI Commercial Waste Processing	35,116	92,230	116	6	4	7,023	Staten Island 3000 TPD WTE	40 cy roll-off truck
SE Brklyn Commercial Waste Processing	229,095	592,937	759	38	4	45,819	Spring Creek WTE 1500 TPD	40 cy roll-off truck
Finscen Recycling Export ⁵	5,611	11,221	19	1	11	3,086	Closest MTS	40 cy roll-off truck
Generic MTS for MRF/Compost Residue ⁶	567,508	1,135,015	1,879	0.96	50	14,551	MSW Landfill	Barge
Staten Island 3000 TPD WTE Overflow ⁷	255,977	443,772	848	0.43	50	6,564	MSW Landfill	Barge
SCENARIO TOTALS	5,117,847	11,337,414	16,618	292.00	25 (Average)	908,709		

Table II-B.2. Transfer Vehicle Miles, Scenario D.

Transferred From	Tons/Year	Volume/Year	Tons Transferred per Day	Loads/Day	Round Trip Miles/Load	Total Annual Transfer Miles	Transferred To	By
West 135th St. MTS	389,442	1,108,825	1,290	0.66	50	9,986	Brooklyn Navy Yard Incinerator	Barge
East 91st St. MTS	183,792	584,978	609	0.31	46	4,336	Brooklyn Navy Yard Incinerator	Barge
West 59th St. MTS	201,740	616,036	668	0.34	42	4,345	Brooklyn Navy Yard Incinerator	Barge
North Shore MTS ^o	661,695	1,644,061	2,191	1.12	56	19,003	Brooklyn Navy Yard Incinerator	Barge
Greenpoint MTS	302,303	785,892	1,001	0.51	43	6,666	Staten Island 3000 TPD WTE	Barge
Hamilton Avenue MTS	560,349	1,316,858	1,855	0.95	34	9,770	Staten Island 3000 TPD WTE	Barge
SW Brooklyn MTS	172,009	447,050	570	0.29	32	2,823	Staten Island 3000 TPD WTE	Barge
Brooklyn Navy Yard Incinerator	167,685	325,918	459	0.24	36	3,096	Ash Landfill	Barge
Staten Island 3000 TPD WTE	106,277	206,564	291	15	8	42,511	Ash Landfill	40 cy roll-off truck
Greenpoint Incinerator	60,692	117,963	166	0.09	43	1,338	Ash Landfill	Barge
Southwest Incinerator	56,567	109,946	155	0.08	32	928	Ash Landfill	Barge
Betts Avenue Incinerator	58,235	113,188	160	8	45	131,029	Ash Landfill	40 cy roll-off truck
NW Bronx 2250 TPD WTE	82,796	160,925	227	11	64	264,947	Ash Landfill	40 cy roll-off truck
Spring Creek 2250 TPD WTE	82,192	159,751	225	11	52	213,699	Ash Landfill	40 cy roll-off truck
Ward's Island 2250 TPD WTE	84,078	163,417	230	12	44	184,972	Ash Landfill	40 cy roll-off truck
Maspeth 1500 TPD WTE	48,830	94,908	134	7	50	122,075	Ash Landfill	40 cy roll-off truck
Betts Commercial Waste Processor	22,847	61,275	76	4	4	4,569	Betts Avenue Incinerator	40 cy roll-off truck
NW Bronx Commercial Waste Processor	312,646	789,647	1,035	52	4	62,529	NW Bronx 2250 TPD WTE	40 cy roll-off truck
SE Brooklyn Commercial Waste Processor	257,202	582,015	852	43	4	51,440	Spring Creek 2250 TPD WTE	40 cy roll-off truck
SI Commercial Waste Processor	214,879	432,592	712	36	4	42,976	Staten Island 3000 TPD WTE	40 cy roll-off truck
SW Commercial Waste Processor	46,666	103,982	155	8	4	9,333	Southwest Incinerator	40 cy roll-off truck
Maspeth Commercial Waste Processor	834,222	1,731,746	2,762	138	4	166,844	Maspeth 1500 TPD WTE	40 cy roll-off truck
Ward's Island Commercial Waste Processor	171,495	435,895	568	28	4	34,299	Ward's Island 2250 TPD WTE	40 cy roll-off truck
Commercial Paper Processing	272,816	545,632	903	45	4	54,563	Closest MTS	40 cy roll-off truck
Commercial High Quality MRFs	73,611	147,222	244	12	4	14,722	Closest MTS	40 cy roll-off truck
Staten Island 3000 TPD WTE Overflow	602,573	1,239,673	1,995	1.02	50	15,451	MSW Landfill	Barge
SCENARIO TOTAL:	6,027,639	14,025,958	19,532	434.00	29 (Average)	1,478,250		

Table II-B.1. and II-B.2. Endnotes

1. 1. Tons per year and volume per year are taken directly from WastePlan reports for Scenarios B and D.

2. This is calculated simply as: Tons/Year " Working Days per Year.

3. Ash from the Brooklyn Navy Yard Incinerator is barged to an ash landfill.

4. Ash from the Greenpoint and Southwest Incinerators is barged to an ash landfill.

5. The amount of waste handled by this facility represents the amount of recyclables that overflow the established residential MRFs. In that sense, this facility represents the amount of overtime these facilities must work in order to handle their under-capacity. The Round Trip Miles/Load represents the average of the distances from the six MRFs. Residue from this facility is also handled twice, and is thus also accounted for at the Generic MTS for MRF/Compost Residue.

6. Residue from the MRFs (including commercial MRFs and paper processing facilities) and In-Vessel compost facilities will be transferred twice in this scenario. The first transfer will be from the facility to a marine transfer station and then from the marine transfer station to Fresh Kills. This facility is created in this table to account for the second transfer. The Round Trip Miles/Load of 50 chosen for this facility represents the average round trip distance from the City's existing marine transfer station to the Fresh Kills landfill, for in reality, every marine transfer station will receive a portion of this total residue; residue will simply be shipped to the MTS the closest to the residue-producing facility. Residue from the Staten Island MRF is not included at this Generic MTS as that facility will truck its residue directly to the landfill.

7. The tons, volumes, and vehicle miles associated with this facility represent the tons that cannot be handled by the City's incineration capacity in 2000. This waste will be sent directly to Fresh Kills from the various marine transfer stations throughout the city. Thus, the Round Trip Miles/Load depicted here represents the average distance from all marine transfer stations to the landfill.

8. The tons handled at this facility include both the 315,270 tons routed directly to the MTS from the collection programs as well as residue from the Commercial Paper Processing and Commercial High Quality MRFs. Residue from these latter facilities was sent to the North Shore MRF for the following reasons. First, residue from those facilities will be handled twice—the first time when they are transferred to the MTS most proximate to them, and the second time when their residue is barged from the MTS to an incinerator. Second, the North Shore MTS had a Round Trip Miles/Load approximately equal to the average travel distance from the seven MTS to their receiving incinerators. Thus, rather than create a generic facility, as was done in Scenario B to handle MRF and composting residue, that residue needing to be handled twice was simply included with the North Shore MTS shipments.

APPENDIX II-C

SOLID WASTE MANAGEMENT FACILITY DATA SHEETS

SOLID WASTE MANAGEMENT TECHNOLOGY CONSULTANTS

Cal Recovery, Hercules, CA

CSI Resource System, Incorporated, Boston, MA

E & A Environmental Consultants, Stoughton, MA

SCS Engineers, Reston, VA

TAMS Consultants, Incorporated, New York, New York

Waste-Tech, Houston, TX

TABLE II-C.1

Facility Name

Materials Recovery Facility

Daily Throughput (tpd)

500

Operating Conditions

Days/year: 302

Availability (%): 100

Average Annual Throughput (tons)

151,000

Inputs into Facility (tpd)

Recyclables

500

Building Square Footage

100,000

Equipment

Energy Type

Units

Mobile Equipment

D

N/A

Bag Breakers

E

3

Conveyers

E

13

Sorting Stations

-

32

Trommels

E

1

Magnetic Separators

E

1

Balers

E

2

Scales

E

1

Energy Used

Electricity (kWh/yr)

2,900,000

Natural Gas (cf/yr)

1,438,095

Propane (cf/yr)

Diesel (gal/yr)

30,200

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

3.60E+10

Average Btu/ton

2.38E+05

Outputs from Facility

Processed recyclables destined for market.

Facility Description

Facility operates 2 shifts/day. Collection is of all recyclables regardless of marketability. Sorts all materials collected: all papers, glass containers, plastics, and metals. Materials are baled, shredded, crushed, or densified and sent to market.

Energy Use

Diesel is used for mobile equipment, natural gas for heating, electricity for process equipment.

Assumptions

Electricity demand based on 20 kWh/ton; natural gas on 0.1 MBtu/ton; diesel on 0.2 gal/ton.

Sources

Cal Recovery.

TABLE II-C.2

Facility Name		Commercial Paper Processing		
Daily Throughput (tpd)		250	500	750
Operating Conditions				
Days/year:	302			
Availability (%):	100			
Average Annual Throughput (tons)		75,500	151,000	226,500
Inputs into Facility (tpd)				
Commercial paper and cardboard		250	500	750
Building Square Footage		22,400	41,700	61,100
Equipment	Energy Type	Units		
Front-end Loaders	D	2	2	3
Forklifts	D	1	2	3
Pick-up Trucks	D	1	1	1
Balers	E	1	2	3
Conveyers	E	1	2	3
Scales	E	1	1	1
Energy Used				
Electricity (kWh/yr)		1,887,500	3,775,000	5,662,500
Natural Gas (cf/yr)		4,070,760	7,715,984	11,370,955
Propane (cf/yr)				
Diesel (gal/yr)		9,362	9,966	13,288
Gasoline (gal/yr)				
Heating Oil (gal/yr)				
Total Btu for Facility (per year)		2.54E+10	4.91E+10	7.32E+10
Average Btu/ton		3.36E+05	3.25E+05	3.23E+05
Outputs from Facility				
Baled Corrugated	Baled Mixed Paper			
Baled Office Paper	Residues			
Baled Newspaper				

Facility Description

Facility operates 2 shifts/day. Commercial paper and cardboard are dumped onto the tipping floor and conveyed through sorting stations that separate out corrugated cardboard, office paper, newspaper, and mixed paper. The sorted materials are baled and prepared for shipment to markets.

Energy Use

Electricity is used to power balers, conveyers and scales; natural gas for heating; deisel for mobile equipment.

Assumptions

Annual diesel fuel based on: 14 gallons/day/front-end loader for three shifts/day; 3 gallons/day/forklift for three shifts/day; 10 gallons/day/pick-up truck. Annual electricity use based on 25 kWh/ton estimate; natural gas from annual cost using \$0.00513/cubic foot conversion.

Sources

CSI; SCS; Tellus

TABLE II-C.3

Facility Name		Materials Buy Back	
Daily Throughput (tpd)		10	50
Operating Conditions			
Days/year:	302		
Availability (%):	100		
Average Annual Throughput (tons)		3,020	15,100
Inputs into Facility (tpd)			
Residential recyclables		10	50
Building Square Footage		6,300	35,100
Equipment	Energy Type	Units	
Forklift	D	1	2
Yard truck	D	1	1
Magnetic can separator	E	1	2
Can flattener	E	1	1
Containers (CY)	-	104	380
Energy Used			
Electricity (kWh/yr)		269,370	800,000
Natural Gas (cf/yr)			
Propane (cf/yr)			
Diesel (gal/yr)		2,720	13,600
Gasoline (gal/yr)			
Heating Oil (gal/yr)			
Total Btu for Facility (per year)		3.20E+09	1.03E+10
Average Btu/ton		1.06E+06	6.82E+05
Outputs from Facility			
ONP	Plastics-Film	Textiles	
OCC	Plastics-Mixed Rigid	Residue	
Other Paper	Aluminum		
Glass Containers	Ferrous		

Facility Description

Facility operates 1 shift/day. Buy back center acts as a transfer station for recyclables.

Revenues collected at MRF where final processing and marketing take place.

Energy Use

Electricity is used to power magnetic can separator and can flattener; deisel for mobile equipment.

Assumptions

Electricity consumption based on annual use; diesel fuel from annual cost using \$1.00/gallon conversion factor.

Sources

CSI.

TABLE II-C.4**Facility Name****Materials Drop-off****Daily Throughput (tpd)****10****50****Operating Conditions**

Days/year: 302

Availability (%): 100

Average Annual Throughput (tons)

3,020

15,100

Inputs into Facility (tpd)

Residential recyclables

10

50

Building Square Footage

6,300

35,100

Equipment**Energy Type****Units**

Forklift

D

1

2

Yard Truck

D

1

1

Can Flattener

E

1

1

Containers (CY)

-

119

452

Energy Used

Electricity (kWh/yr)

137,970

600,000

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr)

1,770

8,851

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

1.69E+09

7.51E+09

Average Btu/ton

5.60E+05

4.97E+05

Outputs from Facility

ONP

Mixed Paper

Ferrous

OCC

Glass Containers

Textiles

Office/CPO

Plastics

OMG/Glossy

Aluminum

Facility Description

Facility operates 1 shift/day. Materials are dropped off by residents and transferred to recycling facilities for processing and marketing.

Energy Use

Electricity to power can flattener; diesel for mobile equipment.

Assumptions

Electricity consumption based on annual use; diesel fuel from annual cost using \$1.00/gallon conversion factor.

Sources

CSI.

TABLE II-C.5

Facility Name

Waste Oil Facility

Daily Throughput (gpd)

1,500

5,000

7,500

Operating Conditions

Days/year: 302

Availability (%): 100

Average Annual Throughput (gals)

453,000

1,510,000

2,265,000

Inputs into Facility (gpd)

Used oil

1,500

5000

7500

Building Square Footage

775

775

775

Equipment

Energy Type

Units

Front-end Loaders

D

1

1

1

Forklifts

D

1

1

1

Pumps

E

3

3

3

Storage Tanks

-

3

3

3

Energy Used

Electricity (kWh/yr)

45,300

151,000

226,500

Natural Gas (cf/yr)

1,949,318

1,949,318

1,949,318

Propane (cf/yr)

Diesel (gal/yr)

1,812

1,812

1,812

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

2.77E+09

3.88E+09

4.68E+09

Average Btu/gallon

6.12E+03

2.57E+03

2.06E+03

Outputs from Facility

Waste oil for processing/disposal.

Facility Description

Facility operates 1 shift/day. Oil received in tankers, 55-gallon drums, or other containers at loading area.

Containers transferred to pump station, and waste oil is pumped to storage tanks. Storage tank size increases with facility size (5,000, 16,667, and 25,000 gallons).

Energy Use

Diesel for mobile equipment; electricity to operate pumps.

Assumptions

Electricity use based on 0.1 kWh/gal; natural gas use derived from annual cost; diesel on 6 gpd.

Sources

CSI.

TABLE II-C.6

Facility Name

Waste Tire Facility

Daily Throughput (tpd)

100

200

300

Operating Conditions

Days/year: 302

Availability (%): 100

Average Annual Throughput (tons)

30,200

60,400

90,600

Inputs into Facility (tpd)

Mixed tires (passenger & truck)

100

200

300

Building Square Footage

15,400

28,500

25,800

Equipment

Energy Type

Units

Front-end Loaders

D

2

2

2

Forklifts

D

1

1

1

Conveyers

E

3

3

4

Shredders

E

2

2

3

Scale

E

1

1

1

Energy Used

Electricity (kWh/yr)

906,000

1,812,000

2,718,000

Natural Gas (cf/yr)

29,239,766

54,580,117

54,580,117

Propane (cf/yr)

Diesel (gal/yr)

6,342

6,342

6,342

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

4.11E+10

7.72E+10

8.65E+10

Average Btu/ton

1.36E+06

1.28E+06

9.55E+05

Outputs from Facility

Shredded tires for disposal.

Facility Description

Facility operates 2 shifts/day. Tires are dumped onto tipping floor, conveyed to shredders, shredded, and conveyed to storage.

Energy Use

Diesel for mobile equipment; electricity for process equipment.

Assumptions

Electricity use based on 30 kWh/ton; natural gas use derived from annual cost; diesel on 21gpd.

Sources

CSI.

TABLE II-C.7

Facility Name

Household Hazardous Waste Drop-Off

Daily Throughput (tpd)

2

Operating Conditions

Days/year: 302

Availability (%): 100

Average Annual Throughput (tons)

604

Inputs into Facility (pounds/day)

Paint 2000

Car Batteries 857

Waste Oil 714

Dry Cells 286

Pesticides 143

Building Square Footage

5,700

Equipment

Energy TypeUnits

Containers

-

72

Forklifts

D

1

Energy Used

Electricity (kWh/yr) 251,076

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr) 1,500

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

2.84E+09

Average Btu/ton

4.71E+06

Outputs from Facility

Same as inputs.

Facility Description

Facility operates 1 shift/day. Input materials are packed and transferred to processing or disposal facilities.

Energy Use

Diesel is used in the forklift; electricity used in general building operations.

Assumptions

Annual electricity use based on annual cost using \$0.05576/kWh conversion; diesel fuel from annual cost using \$1.00/gallon.

Sources

CSI.

TABLE II-C.8

Facility Name

Mixed Waste Processing (Organics in Waste)

Daily Throughput (tpd)

1,000

2,250

3,000

Operating Conditions

Days/year: 365

Availability (%): 85

Average Annual Throughput (tons)

310,250

698,063

930,750

Inputs into Facility (tpd)

Mixed solid waste

1,000

2,250

3,000

Building Square Footage

55,000

123,750

165,000

Equipment

Energy Type

Units

Mobile Equipment

D

N/A

N/A

N/A

Conveyers

E

24

54

72

Sorting Stations

-

10

22.50

30

Trommels

E

1

2.25

3

Magnetic Separators

E

2

4.50

6

Balers/Compactors

E

2

4.50

6

Destoner

E

1

2.25

3

Energy Used

Electricity (kWh/yr)

6,205,000

13,961,250

18,615,000

Natural Gas (Cf/yr)

Propane (Cf/yr)

Diesel (gal/yr)

62,050

139,612

186,150

Gasoline (gal/yr)

Heating Oil (gal/yr)

22,161

49,862

66,482

Total Btu for Facility (per year)

7.73E+10

1.74E+11

2.32E+11

Average Btu/ton

2.49E+05

2.49E+05

2.49E+05

Outputs from Facility

Processed recyclables, composted organic materials, residual waste.

Facility Description

Facility operates 3 shifts/day. Recyclables and compostables are sorted from delivered mixed waste.

Recyclables are processed and sent to market. Compostables are sent to a composting facility.

Energy Use

Electricity is used to power all but mobile equipment; diesel for mobile equipment; oil for heating.

Assumptions

Annual electricity use based on 20 kWh/ton; heating fuel on 0.01 MMBtu/ton; diesel use on 0.2 gallons/ton.

Sources

Cal Recovery.

TABLE II-C.9

Facility Name

Mixed Waste Processing (Organics Separated)

Daily Throughput (tpd)

1,000

2,250

3,000

Operating Conditions

Days/year: 365

Availability (%): 85

Average Annual Throughput (tons)

310,250

698,063

930,750

Inputs into Facility (tpd)

Waste materials without organic material

1,000

2,250

3,000

Building Square Footage

55,000

123,750

165,000

Equipment

Energy Type

Units

Mobile Equipment

D

N/A

N/A

N/A

Conveyers

E

24

54

72

Sorting Stations

-

13

29.25

39

Trommels

E

1

2.25

3

Magnetic Separators

E

2

4.50

6

Balers/Compactors

E

2

4.50

6

Destoner

E

1

2.25

3

Energy Used

Electricity (kWh/yr)

6,205,000

13,961,250

18,615,000

Natural Gas (Cf/yr)

Propane (Cf/yr)

Diesel (gal/yr)

62,050

139,612

186,150

Gasoline (gal/yr)

Heating Oil (gal/yr)

22,161

49,862

66,482

Total Btu for Facility (per year)

7.73E+10

1.74E+11

2.32E+11

Average Btu/ton

2.49E+05

2.49E+05

2.49E+05

Outputs from Facility

Processed recyclables destined for market, waste residuals destined for disposal.

Facility Description

Facility operates 3 shifts/day. NOTE: The difference between the organics-in and the organics-separated facilities is that organics-separated has more sorting stations. Mixed waste is delivered to facility without organic materials. Recyclables are sorted from mixed waste, processed, and sent to market. Remaining materials are sent to disposal.

Energy Use

Electricity is used to power all but mobile equipment; diesel for mobile equipment; oil for heating.

Assumptions

Annual electricity use based on 20 kWh/ton; heating oil on 0.01 MBtu/ton; diesel use on 0.2 gallons/ton.

Sources

Cal Recovery.

TABLE II-C.10

Facility Name

Commercial Waste Processor

Daily Throughput (tpd)

1,500

Operating Conditions

Days/year: 312

Availability (%): 100

Average Annual Throughput (tons)

468,000

Inputs into Facility (tpd)

Mixed commercial waste

1,500

Building Square Footage

150,000

Equipment

Energy Type

Units

Pick-Up Truck

G

1

Mobile Equipment

D

7

Conveyers

E

3

Handsorting Stations

-

N/A

Trommels

E

1

Magnetic Separators

E

1

Balers

E

1

Densifiers

E

2

Scales

E

1

Energy Used

Electricity (kWh/yr)

5,241,600

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr)

34,730

Gasoline (gal/yr)

19,533

Heating Oil (gal/yr)

Total Btu for Facility (per year)

6.23E + 10

Average Btu/ton

1.33E + 05

Outputs from Facility

Densified aluminum, ferrous, baled paper, corrugated and plastics, wood chips, and commercial waste.

Facility Description

Facility operates 2 shifts/day. Mixed commercial waste is hand sorted for recovery of recyclables. Recovered materials are processed (see Outputs). Remaining waste is transferred to disposal. Number of handsorting stations not specified.

Energy Use

Diesel is used for mobile equipment; gasoline for pick-ups; electricity is used in all other equipment. mobile equipment.

Assumptions

Electricity demand based on annual use; diesel fuel use estimated at 115 gpd; gasoline use at 0.07 gpd/\$1000 of vehicles.

Sources

Cal Recovery, TAMS, CSI.

TABLE II-C.11

Facility Name		Mixed Waste Composting
Daily Throughput (tpd)		1,500
Operating Conditions		
Days/year:	365	
Availability (%):	85	
Average Annual Throughput (tons)		465,375
Inputs into Facility (tpd)		
MSW		1,500
Building Square Footage		575,630
Equipment	Energy Type	Units
Mobile Equipment	D	N/A
Drum Composters	E	5
Aeration	E	N/A
Conveyers	E	30
Biofilters/fans	E	N/A
Bag Breakers	E	5
Sorting Stations	-	20
Magnetic Separators	E	5
Balers/Compactors	E	2
Scales	E	1
Energy Used		
Electricity (kWh/yr)		21,900,000
Natural Gas (cf/yr)		
Propane (cf/yr)		365,664
Diesel (gal/yr)		
Gasoline (gal/yr)		
Heating Oil (gal/yr)		36,000
Total Btu for Facility (per year)		2.34E + 11
Average Btu/ton		5.03E + 05

Outputs from Facility

Composted materials with limited applications; recyclables; residuals.

Facility Description

Facility operates 2 shifts/day. Recyclables sorted from incoming waste stream, remaining material is composted.

Energy Use

Electricity used to operate process equipment; diesel fuel for mobile equipment.

Assumptions

All energy demands based on annual electricity/fuel use. [1]

Notes

[1] Based on 1992 site visits, B. Liebowitz of the Energy Authority cites electricity usage of 47 kWh/ton at the Fairfield CT grass/sludge compost facility (12,480 tpy), versus 100 kWh/ton at the New Milford, CT food processing residue compost facility (5475 tpy). The latter assumes exhaust fans and two aerators operating 24 hours/day, 365 days/year and was therefore not considered a representative value.

Sources

E & A, Cal Recovery.

TABLE II-C.12

Facility Name

In-Vessel Compost (Source-Separated Organics)

Daily Throughput (tpd)

600

900

1,500

Operating Conditions

Days/year: 365

Availability (%): 100

Average Annual Throughput (tons)

219,000

328,500

547,500

Inputs into Facility (tpd)

Source-separated organic materials

600

900

1,500

Building Square Footage

218,252

327,378

545,630

Equipment

Energy Type

Units

Front-end Loaders

D

6

6

6

Drum Composters

E

2

3

5

Conveyers

E

20

20

20

Screens

E

2

2

2

Blowers

E

2

2

2

Destoner

E

1

1

1

Energy Used

Electricity (kWh/yr)

8,760,000

13,140,000

21,900,000

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr)

42,040

63,060

105,100

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

9.77E+10

1.47E+11

2.44E+11

Average Btu/ton

4.46E+05

4.46E+05

4.46E+05

Outputs from Facility

Compost marketed as soil ammendment with limited applications.

Facility Description

Facility operates 2 shifts/day. Source separated organic materials are delivered to the facility, processed in a Dano drum, aerated in special aeration buildings, cured, and screened.

Energy Use

Diesel is used in mobile equipment, electricity is used in all other applications.

Assumptions

Energy demand for 1500 tpd facility based on annual use.[1] Fuel units for 600 tpd and 900 tpd facilities are 40% and 60% of 1500 tpd facility, respectively.

Notes

[1] Based on 1992 site visits, B. Liebowitz of the Energy Authority cites electricity usage of 47 kWh/ton at the Fairfield CT grass/sludge compost facility (12,480 TPY), versus 100 kWh/ton at the New Milford, CT food processing residue compost facility (5475 TPY). The later assumes exhaust fans and two aerators operating 24 hours/day, 365 days/year and was therefore not considered a representative value.

Sources

Cal Recovery; E & A.

TABLE II-C.13

Facility Name		Leaf and Yard Composting
Daily Throughput (tpd)		N/A
Operating Conditions		
Days/year:	302	
Availability (%):	100	
Average Annual Throughput (tons)		20,000
Inputs into Facility (tpd)		
Leaves (24.6%)	Brush (20.3%)	
Grass Clippings (55.1%)		
Building Square Footage		3,840
Equipment	Energy Type	Units
Front-end Loaders	D	3
FEL Rollout Buckets	-	2
Dump Trucks	D	3
Water Trucks	D	1
Composter	D	1
Pre-processing Equipment:		
Shear Shredders	E	1
Ferrous Removal Sys.	E	1
Conveyers	E	4
Rotary Trommels	D	1
Post-processing Equipment:		
Rotary Trommel	D	1
Scales	E	1
Energy Used		
Electricity (kWh/yr)		936,200
Natural Gas (Cf/yr)		
Propane (Cf/yr)		
Diesel (gal/yr)		124,424
Gasoline (gal/yr)		
Heating Oil (gal/yr)		
Total Btu for Facility (per year)		2.69E + 10
Average Btu/ton		1.35E + 06

Outputs from Facility

Compost marketed as soil ammendment with wide applications.

Facility Description

Facility operates 1 shift/day. Materials are pre-processed using shredder/trommel equipment, and then placed in windrows. Windrows are formed using tandem trucks and turned using a compost turning machine. Windrows are turned, initially weekly or bi-weekly, and less often as time progresses. Composting continues for 4 to 6 months. Composted material is screened through post-processing equipment to remove any oversized particles.

Energy Use

Electricity is used to power pre-processing equipment; diesel for mobile and post-processing equipment.

Assumptions

Electricity and fuel demands based on annual use. [1]

Notes

[1] Based on 1992 site visits, B. Liebowitz of the Energy Authority cites electricity usage of 47 kWh/ton at the Fairfield CT grass/sludge compost facility (12,480 tpy), versus 100 kWh/ton at the New Milford, CT food processing residue compost facility (5475 tpy). The latter assumes exhaust fans and two aerators operating 24 hours/day, 365 days/year and was therefore not considered a representative value.

Sources

E & A.

TABLE II-C.14

Facility Name		Sludge Compost			
		25	50	100	250
Daily Throughput (tpd)					
Operating Conditions					
Days/year:	365				
Availability (%):	100				
Average Annual Throughput (tons)		9,125	18,250	36,500	91,250
Inputs into Facility (tpd)					
Sludge		25	50	100	250
Building Square Footage		137,500	260,000	400,000	1,059,000
Equipment	Energy Type	Units			
Mobile Equipment	D	N/A	N/A	N/A	N/A
Aeration Systems	E	N/A	N/A	N/A	N/A
Live Bins	E	7	14	28	62
Sludge Mixers	E	2	2	2	2
Screens	E	1	2	4	12
Conveyers	E	N/A	N/A	N/A	N/A
Odor Control	E	N/A	N/A	N/A	N/A
Energy Used					
Electricity (kWh/yr)		5,934,000	11,406,000	22,510,000	49,277,904
Natural Gas (cf/yr)					
Propane (cf/yr)					
Diesel (gal/yr)		62,250	124,400	250,000	375,000
Gasoline (gal/yr)					
Heating Oil (gal/yr)					
Total Btu for Facility (per year)		7.08E+10	1.37E+11	2.71E+11	5.69E+11
Average Btu/ton		7.76E+06	7.51E+06	7.42E+06	6.23E+06

Outputs from Facility

Soil ammdement for use in limited applications.

Facility Description

Facility operates 1 shift/day. Sludge is mixed with bulking agent and placed in live bins where aeration system provides optimal oxygen conditions for compost process.

Energy Use

Diesel is used in mobile equipment; electricity is used for all other equipment.

Assumptions

Source did not provide a detailed breakdown of equipment requirements; energy demand based on annual use.

Sources

E & A.

TABLE II-C.15

Facility Name		Sludge Pelletizer	
Daily Throughput (tpd)		150	500
Operating Conditions			
Days/year:	365		
Availability (%):	100		
Average Annual Throughput (tons)		54,750	182,500
Inputs into Facility (tpd)			
Sludge		150	500
Building Square Footage		37,300	78,800
Equipment	Energy Type	Units	
Drying Equipment	G	10	35
Sludge Storage	-	N/A	N/A
Product Storage	-	N/A	N/A
Conveyers	E	600SF	2000SF
Scales	E	1	1
Odor Control Equipment	E	7	18
Crane	E	1	1
Energy Used			
Electricity (kWh/yr)		20,600,000	65,900,000
Natural Gas (cf/yr)		1,291,731,600	4,307,000,400
Propane (cf/yr)			
Diesel (gal/yr)			
Gasoline (gal/yr)			
Heating Oil (gal/yr)			
Total Btu for Facility (per year)		1.57E+12	5.21E+12
Average Btu/ton		2.87E+07	2.86E+07

Outputs from Facility

Sludge pellets marketed as a soil supplement with limited applications.

Facility Description

Facility operates 2 shifts/day. Sludge is dried, stablized, and pelletized.

Energy Use

Natural gas used for drying sludge, electricity used in all other applications according to source.

Assumptions

Electricity demand based on annual use; natural gas consumption based on 1,076,443 100 cf/month for 150 tpd facility and 3,589,167 100cf/month for 500 tpd facility.

Sources

E & A.

TABLE II-C.16

Facility Name

Sludge Chemical Stabilization

Daily Throughput (dry tpd)

35

115

500

Operating Conditions

Days/year: 365

Availability (%): 100

Average Annual Throughput (tons)

12,775

41,975

182,500

Inputs into Facility (dry tpd)

Anaerobically Digested Sludge
(25% solids)

35

115

500

Building Square Footage

39,900

67,500

277,242

Equipment

Energy Type

Units

Front-end Loaders

D

1

1

2

Windrow Turners

D

1

1

1

Mixers

E

4

8

12

Conveyers

E

N/A

N/A

N/A

Silos

-

N/A

N/A

N/A

Sludge Bins

-

N/A

N/A

N/A

Scales

E

1

1

1

Odor Control System

E

N/A

N/A

N/A

Energy Used

Electricity (kWh/yr)

1,600,000

2,262,500

16,233,800

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr)

146,400

235,200

278,000

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

3.69E+10

5.60E+10

2.09E+11

Average Btu/ton

2.89E+06

1.33E+06

1.15E+06

Outputs from Facility

Landfill cover; agricultural lime supplement

Facility Description

Facility operates 3 shifts/day. From initial storage bins, dewatered sludge is conveyed to mixers and combined with quicklime (CaO). This sludge/lime mixture is blended with cement kiln dust (CKD) and windrowed for seven days, and stored until it can be transported off site. Results in material with consistency of granular soil used for limited land

Energy Use

Diesel is used in mobile equipment, electricity is used for all other equipment.

Assumptions

Utilities reported in units per year; disaggregated fuel information (diesel and heating oil) unavailable for 35 and 115 tpd facilities; total facility Btu calculated as diesel fuel.

Sources

E&A.

TABLE II-C.17

Facility Name

Construction and Demolition Debris Processing

Daily Throughput (tpd)

500

Operating Conditions

Days/year: 312

Availability (%): 100

Average Annual Throughput (tons)

156,000

Inputs into Facility (tpd)

Construction and demolition debris

500

Building Square Footage

50,000

Equipment

Energy Type

Units

Front-end Loaders	D	3
Backhoe w/ Hammer	D	1
Sweeper	D	1
Shredders	E	1
Washers	E	2
Balers	E	1
Conveyers	E	1
Hammermills	E	1
Magnetic Separator	E	1
Wood Chip Screen	E	1
Jaw Crusher	E	1
Scales	E	2

Energy Used

Electricity (kWh/yr) 66,440

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr) 21,840

Gasoline (gal/yr)

Heating Oil (gal/yr) 12,600

Total Btu for Facility (per year)

5.33E+09

Average Btu/ton

3.42E+04

Outputs from Facility

Wood	Brick	Lead
Steel	OCC	Tree/Brush
Aluminum Sheet	Aggregate	Residue

Facility Description

Facility operates 3 shifts/day. Material is dumped onto tipping area, conveyed to process area. After recyclables are separated from the waste, material is held in a storage area until it can be transported to market.

Energy Use

Diesel is used for mobile equipment; heating oil for heating; electricity for all other equipment.

Assumptions

Energy demand based on annual use of electricity and fuels.

Sources

SCS.

TABLE II-C.18

Facility Name		Harbor Debris Processing
Daily Throughput (tpd)		150
Operating Conditions		
Days/year:	260	
Availability (%):	100	
Average Annual Throughput (tons)		39,000
Inputs into Facility (tpd)		
Harbor debris		150
Building Square Footage		20,000
Equipment	Energy Type	Units
Front-end Loaders	D	1
Sweepers	D	1
Tractor & Transfer Trailers	D	1
Mobile Jaw Cranes (sm.)	D	1
Mobile Jaw Cranes (lg.)	D	1
Chain Saws	D	4
Shredders	E	1
Lumber Mill Saws	E	1
Hammermills	E	1
Magnetic Separators	E	1
Jaw Crushers	E	1
Scales	E	1
Energy Used		
Electricity (kWh/yr)		54,360
Natural Gas (cf/yr)		
Propane (cf/yr)		
Diesel (gal/yr)		21,140
Gasoline (gal/yr)		
Heating Oil (gal/yr)		18,120
Total Btu for Facility (per year)		5.82E+09
Average Btu/ton		1.49E+05
Outputs from Facility		
Facility Description		
Facility operates 2 shifts/day.		
Energy Use		
Diesel for mobile equipment; electricity for process equipment; heating oil for heating.		
Assumptions		
Electricity demand and fuel use based on annual consumption.		
Sources		
SCS.		

TABLE II-C.19

Facility Name		Dredged Spoils Dewatering
Daily Throughput (cubic yards/day)		262
Operating Conditions		
Days/year:	365	
Availability (%):	100	
Average Annual Throughput (cy)		95,630
Inputs into Facility (cubic yards)		
Dredge spoils		159,000
Building Square Footage		
Equipment	Energy Type	Units
Front-end Loaders	D	1
Bulldozer	D	1
Barge Unloader	E	1
Energy Used		
Electricity (kWh/yr)		152,100
Natural Gas (cf/yr)		
Propane (cf/yr)		
Diesel (gal/yr)		8,740
Gasoline (gal/yr)		
Heating Oil (gal/yr)		
Total Btu for Facility (per year)		2.80E+09
Average Btu/cubic yard		2.92E+04

Outputs from Facility

Dewatered materials to be used as landfill cover.

Facility Description

Facility operates 2 shifts/day. Dredged materials transported to dewatering site by barge. During hydraulic off loading phase (approx. 2 months) hydraulic pump out unit transports dredged materials from barge to dewatering basin. During subsequent crust management phase (4 months/year) solids are separated from dredged spoils in dewatering and settling basins. At end of season, settled solids are removed from settling basin and loaded onto trucks for offsite transport (material removal phase approx. 3 months/year). Decant phase lasts 3 months.

Energy Use

Electricity for pumping; diesel for loader and dozer.

Assumptions

Electricity use based on 0.956 kWh/cy; diesel on 0.055 gallons/cubic yard.

Sources

E & A.

TABLE II-C.20

Facility Name

Truck Transfer Station

Daily Throughput (tpd)

1500

Operating Conditions

Days/year: 302

Availability (%): 100

Average Annual Throughput (tons)

453,000

Inputs into Facility (tpd)

MSW 1,500

Building Square Footage

15,000

Equipment

Energy Type

Units

Front-end Loaders D 3

Fixed Cranes D 1

Compacter E 1

Axle Scales E 1

Platform Scales E 2

Energy Used

Electricity (kWh/yr) 1,209,510

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr) 12,684

Gasoline (gal/yr)

Heating Oil (gal/yr) 12,600

Total Btu for Facility (per year)

1.61E+10

Average Btu/ton

3.55E+04

Outputs from Facility

Compacted waste materials.

Description of Facility

Facility operates 3 shifts/day. Facility will handle 1500 tpd for 24 hours/day; each of the machines used only about 50% of the time that the facility operates, and maintenance is performed when the machinery is not being used.

Materials are baled and transferred by truck to disposal facilities.

Energy Use

Electricity is used to power scales and compacters; diesel for mobile equipment.

Assumptions

Annual electricity use based on 2.67 kWh/ton estimate. Diesel fuel use estimated at 42 gallons/day; heating fuel on annual use.

Sources

SCS.

TABLE II-C.21

Facility Name		Rail Transfer Station
Daily Throughput (tpd)		1500
Operating Conditions		
Days/year:	302	
Availability (%):	100	
Average Annual Throughput (tons)		453,000
Inputs into Facility (tpd)		
MSW		1,500
Building Square Footage		19,200
Equipment	Energy Type	Units
Front-end Loaders	D	1
Forklifts	D	3
Fixed Cranes	D	1
Straddle Cranes	D	1
Balers	E	2
Platform Scales	E	2
Containers	N/A	75
Energy Used		
Electricity (kWh/yr)		1,508,490
Natural Gas (cf/yr)		
Propane (cf/yr)		
Diesel (gal/yr)		6,040
Gasoline (gal/yr)		
Heating Oil (gal/yr)		12,600
Total Btu for Facility (per year)		1.83E+10
Average Btu/ton		4.04E+04
Outputs from Facility		
Baled mixed waste.		
Description of Facility		
Facility operates 3 shifts/day. Facility will handle 1500 tpd for 24 hours/day; each of the machines used only about 50% of the time that the facility operates, and maintenance is performed when the machinery is not being used. Materials are baled and loaded on to trains for export out of the region.		
Energy Use		
Electricity is used to power balers and scales; heating oil for heating; diesel for mobile equipment and cranes.		
Assumptions		
Annual electricity use based on 3.33 kWh/ton estimate. Diesel fuel use estimated at 20 gallons/day; natural gas on annual use.		
Sources		
SCS.		

TABLE II-C.22

Facility Name

Marine Transfer Station

Daily Throughput (tpd)

2000

Operating Conditions

Days/year: 302

Availability (%): 100

Average Annual Throughput (tons)

604,000

Inputs into Facility (tpd)

MSW 2,000

Building Square Footage

-

Equipment

Energy TypeUnits

Mobile Equipment

D/G

N/A

Scales

E

2

Energy Used

Electricity (kWh/yr) 640,240

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr) 3,020

Gasoline (gal/yr)

Heating Oil (gal/yr) 54,360

Total Btu for Facility (per year)

1.42E + 10

Average Btu/ton

2.35E + 04

Outputs from Facility

Compacted MSW.

Description of Facility

Facility operates 3 shifts/day. Facility will handle 1500 tpd for 24 hours/day; each of the machines used only about 50% of the time that the facility operates, and maintenance is performed when the machinery is not being used.

Materials are transported from the facility to disposal on Staten Island by marine transfer vessels. Breakdown of mobile equipment not available.

Energy Use

Electricity is used to power scales; diesel for most mobile equipment, gasoline for pick-up trucks (majority is diesel).

Assumptions

Annual electricity use based on 1.06 kWh/ton estimate. Diesel fuel use estimated 10 gallons/day; heating oil on 0.09 gallons/ton.

Sources

SCS.

TABLE II-C.23

Facility Name

MSW Mass-Burn Incinerator

Daily Throughput (tpd)		1,000	2,250	3,000
Operating Conditions				
Days/year:	365			
Availability (%):	85			
Average Annual Throughput (tons)		310,250	698,063	930,750
Inputs into Facility (tpd)				
MSW		1,000	2,250	3,000
Building Square Footage		174,240	217,800	283,140
Equipment	Energy Type	Units		
Combustion Equipment				
Furnace/Boiler	E	2 (500 tpd)	3 (750 tpd)	4 (750 tpd)
Electrical Gen. Equipment				
Turbine Gen. Size (MW)	E	28	62	92
Dry Scrubber	E	2	3	4
Baghouse Filter	E	2	3	4
Flue Gas Ducting & Fan	E	2	3	4
De-NOX System	E	2	3	4
Mercury Removal	E	3	3	4
Monitoring Equipment	E	2	3	4
Compressed Air System	E	1	1	1
Scales	E	1	1	1
Energy Used				
Electricity (kWh/yr)		48,180,000	109,500,000	204,984,000
Natural Gas (cf/yr)				
Propane (cf/yr)				
Diesel (gal/yr)				
Gasoline (gal/yr)				
Heating Oil (gal/yr)				
Total Btu for Facility (per year)		5.06E+11	1.15E+12	2.15E+12
Average Btu/ton		1.63E+06	1.65E+06	2.31E+06

Outputs from Facility

Steam/electricity; MSW incinerator ash destined for disposal at a secured ashfill.

Facility Description

Facility operates 3 shifts/day. Combustion and electrical generation equipment are highly proprietary and therefore were not provided in disaggregated form. Combustion equipment includes: furnace & boilers, ash handling system, boiler, feedwater and treatment system, process piping, cooling tower and auxiliaries, instrumentation and controls. Electrical generation equipment includes: turbine generator and auxiliaries, electrical primary and secondary systems. Cranes are stationary and considered part of combustion equipment. Small equipment (front-end loaders, sweepers, etc.) are annualized as part of maintenance costs, and not provided in disaggregated form.

Energy Use

Electricity is used to power the majority of the equipment. Some natural gas and diesel are probably also used in the process, though none is reported by the source, indicating that these fuel sources may be negligible compared to electricity usage.

Assumptions

Although facility generates electricity, it also requires electricity. Electricity number estimates internal use of electricity and is used to evaluate losses of revenue from potential sale of this energy. Though mobile equipment is also used, diesel usage is considered negligible by the source in terms of energy usage relative to electricity usage.

Sources

TAMS Consultants, Inc.

TABLE II-C.24

Facility Name

MSW - Refuse Derived Fuel Incinerator

Daily Throughput (tpd)		1,000	2,250	3,000
Operating Conditions				
Days/year:	365			
Availability (%):	85			
Average Annual Throughput (tons)		310,250	698,063	930,750
Inputs into Facility (tpd)				
MSW		1,000	2,250	3,000
Building Square Footage		217,800	348,480	588,060
Equipment	Energy Type	Units		
Combustion Equipment				
Process Trains	E	2 (30 tpd)	2 (85 tpd)	3 (100 tpd)
Furnace/Boilers	E	2 (400 tpd)	3 (600 tpd)	4 (600 tpd)
Electrical Gen. Equipment				
Turbine Gen. Size (MW)	E	20	56	93
Dry Scrubber	E	2	3	4
Baghouse Filter	E	2	3	4
Flue Gas Ducting & Fan	E	2	3	4
De-NOX System	E	2	3	4
Mercury Removal	E	3	3	4
Monitoring Equipment	E	2	3	4
Compressed Air System	E	1	1	1
Scales	E	1	1	1
Energy Used				
Electricity (kWh/yr)		27,857,499	62,679,418	83,572,498
Natural Gas (cf/yr)				
Propane (cf/yr)				
Diesel (gal/yr)				
Gasoline (gal/yr)				
Heating Oil (gal/yr)				
Total Btu for Facility (per year)		2.93E+11	6.58E+11	8.78E+11
Average Btu/ton		9.43E+05	9.43E+05	9.43E+05

Outputs from Facility

Electricity and MSW Landfill Ash

Facility Description

Facility operates 3 shifts/day. Combustion and electrical generation equipment are highly proprietary and thus data were not provided in disaggregated form. Combustion equipment includes: RDF production equipment, furnace and boilers, processing trains, ash handling system, boiler feedwater and treatment system, process piping, cooling tower and auxiliaries, instrumentation and controls. Electrical generation equipment includes: turbine generator and auxiliaries, electrical primary and secondary systems. Cranes are stationary and considered part of combustion equipment. Small equipment (front-end loaders, sweepers, etc.) are annualized as part of maintenance costs, and not provided in disaggregated form.

Energy Use

Electricity is used to power most of the equipment. Some natural gas and diesel are probably also used in the process though none is reported by the source, indicating that these fuel sources may be negligible compared to electricity usage.

Assumptions

Although the facility generates electricity, it also requires electricity. Units shown are net electrical use using data provided by the Energy Authority. Diesel fuel use is insignificant compared to electricity.

Sources

The Energy Authority., TAMS Consultants, Inc.

TABLE II-C.25

Facility Name		MSW Modular Incinerator
Daily Throughput (tpd)		360
Operating Conditions		
Days/year:	365	
Availability (%):	85	
Average Annual Throughput (tons)		111,690
Inputs into Facility (tpd)		
MSW		360
Building Square Footage		87,120
Equipment	Energy Type	Units
Combustion		
Boilers	E	3
Electrical Gen. Equipment	E	
Emission Control	E	4
De-NOX System	E	4
Mercury Removal	E	4
Energy Used		
Electricity (kWh/yr)		844,000
Natural Gas (cf/yr)		
Propane (cf/yr)		
Diesel (gal/yr)		
Gasoline (gal/yr)		
Heating Oil (gal/yr)		
Total Btu for Facility (per year)		8.86E + 09
Average Btu/ton		7.93E + 04

Outputs from Facility

Electricity/steam, ash destined for disposal.

Facility Description

Facility operates 3 shifts/day. Facility operates in much the same way that a mass burn incinerator, though modular facilities are usually smaller and more easily expanded. Material are tipped on a tipping floor, burned in a boiler/process room (where air emissions are carefully controlled) and residual ash is transferred to disposal.

Energy Use

Source reports consumption of heating oil for auxiliary and vehicles.

Assumptions

Although facility generates electricity, it also requires electricity. Electricity based on annual use; annual diesel fuel use based on estimate of 197 gpd.

Sources

TAMS Consultants, Inc.

TABLE II-C.26

Facility Name

Regional Pathological Incinerator

Daily Throughput (tpd)

8

Operating Conditions

Days/year: 365

Availability (%): 85

Average Annual Throughput (tons)

2,482

Inputs into Facility (tpd)

Pathological waste

8

Building Square Footage

4,800

Equipment

Energy Type

Units

Combustion Equipment:

E

Path. Incinerators

2 (500lbph)

Pollution Control Equip.

E

Dry Scrubbers

2

Baghouse Filters

8

Energy Used

Electricity (kWh/yr)

402,930

Natural Gas (cf/yr)

17,094,000

Propane (cf/yr)

Diesel (gal/yr)

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

2.21E+10

Average Btu/ton

8.92E+06

Outputs from Facility

Incinerator ash

Facility Description

Facility operates 2 shifts/day. Waste dumped onto the delivery area, automatically fed to incinerators.

Cold storage area for waste storage. Incinerators: two 500 lb/hr pathological waste incinerators with feeders.

Energy Use

Electricity for process equipment; natural gas used for waste destruction/auxiliary heat.

Assumptions

Electricity is annual use; natural gas based on 1,424,500 cf/month.

Sources

Waste Tech.

TABLE II-C.27

Facility Name

Regional Medical Waste Incinerator

Daily Throughput (tpd)

330

Operating Conditions

Days/year: 365

Availability (%): 85

Average Annual Throughput (tons)

102,383

Inputs into Facility (tpd)

Medical waste

330

Building Square Footage

37,100

Equipment

Energy Type

Units

Combustion Equipment:

E

Incinerators

2

Boilers

4

Electrical Generation Equip.:

E

Turbine Generators

2

Pollution Control Equip.

E

Dry Scrubbers

2

Baghouse Filters

8

De-NOX

2

Energy Used

Electricity (kWh/yr)

6,132,000

Natural Gas (cf/yr)

76,230,000

Propane (cf/yr)

Diesel (gal/yr)

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

1.44E+11

Average Btu/ton

1.41E+06

Outputs from Facility

Incinerator ash

Facility Description

Facility operates 3 shifts/day. Waste dumped onto the delivery area, automatically fed to incinerators.

Cold storage area for waste storage. Incinerators: two 500 lb/hr pathological waste incinerators with feeders.

Energy Use

Mass burn type facility. Electricity for process equipment; natural gas used for auxillary heat.

Assumptions

Although facility generates electricity, it also requires electricity. Electricity use shown are losses (from potential revenue) from electrical use; natural gas based on 6,352,500 cf/month.

Sources

Waste Tech, TAMS.

TABLE II-C.28

Facility Name

On-Site Medical Waste Incinerator

Daily Throughput (tpd)

5.4

Operating Conditions

Days/year: 365

Availability (%): 100

Average Annual Throughput (tons)

1,971

Inputs into Facility (tpd)

w

5.4

Building Square Footage

4,800

Equipment

Energy Type

Units

Conveyers

E

N/A

Combustion Equipment:

E

Incinerators

1

Pollution Control Equip.

E

Wet Venturi Scrubbers

N/A

Waste Handling Equip.

N/A

Waste Water Treat. Equip.

N/A

Energy Used

Electricity (kWh/yr)

116,738

Natural Gas (cf/yr)

1,200,000

Propane (cf/yr)

Diesel (gal/yr)

Gasoline (gal/yr)

6,707

Heating Oil (gal/yr)

Total Btu for Facility (per year)

3.36E + 09

Average Btu/ton

1.70E + 06

Outputs from Facility

Incinerator ash

Facility Description

Facility operates 1 shift/day. Process equipment: one 5,500,000 Btu/hr dual chamber controlled air incinerator with feeder. Other process equipment not identified.

Energy Use

Electricity for process equipment; natural gas necessary for preheating and temperature maintenance.

Assumptions

Electricity and gasoline based on annual use; natural gas based on 100,000 cf/month.

Sources

Waste Tech.

TABLE II-C.29

Facility Name

Sludge Incinerator

Daily Throughput (tpd)

250**Operating Conditions**

Days/year: 302

Availability (%): 100

Average Annual Throughput (tons)

75,500

Inputs into Facility (tpd)

Sludge

250

Building Square Footage

43,560

Equipment

Energy TypeUnits

Lump Sum Reported

Energy Used

Electricity (kWh/yr)

6,030,000

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr)

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

6.33E + 10

Average Btu/ton

8.38E + 05

Outputs from Facility

Ash

Facility Description

Facility operates 2 shifts/day. Sludge is incinerated and disposed in special secure landfill.

Energy Use

Incinerator equipment operates on electricity; natural gas is auxiliary fuel.

Assumptions

Electricity is annual use; annual natural gas use based on 10,800 cf/month.

Sources

Stone and Webster, TAMS.

TABLE II-C.30

Facility Name

Sludge/MSW Landfill

Daily Throughput (tpd)

5,000

Operating Conditions

Days/year: 302

Availability (%): 100

Average Annual Throughput (tons)

1,510,000

Inputs into Facility (tpd)

MSW and sludge

5,000

Building Square Footage

28,600

Equipment

Energy Type

Units

Front-end Loaders

D

6

Bulldozers

D

6

Pick-up Trucks

D

2

Off-highway Trucks

D

4

Graders

D

2

Sweepers

D

1

Water Wagons

D

1

Compactors

D

4

Pump Stations

E

5

Storage Tanks

-

350,000 gal

Scales

E

6

Energy Used

Electricity (kWh/yr)

329,180

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr)

84,870

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

1.51E+10

Average Btu/ton

9.97E+03

Outputs from Facility

None

Facility Description

Facility operates 1 shift/day. Materials are dumped from trucks, compacted, and covered.

Energy Use

Diesel fuel is used in mobile equipment; electricity is for pump stations and scales.

Assumptions

Energy demand based on annual use.

Sources

SCS.

TABLE II-C.31

Facility Name

Ash Landfill

Daily Throughput (tpd)

1,000

Operating Conditions

Days/year: 312

Availability (%): 100

Average Annual Throughput (tons)

312,000

Inputs into Facility (tpd)

Incinerator ash

1,000

Building Square Footage

11,200

Equipment

Energy TypeUnits

Front-end Loaders

D

2

Bulldozers

D

2

Pick-up Trucks

D

2

Sweepers

D

1

Water Wagons

D

1

Compactors

D

1

Pump Stations

E

6

Storage Tanks

-

350,000 gal

Scales

E

2

Energy Used

Electricity (kWh/yr)

116,572

Natural Gas (cf/yr)

Propane (cf/yr)

Diesel (gal/yr)

20,838

Gasoline (gal/yr)

Heating Oil (gal/yr)

Total Btu for Facility (per year)

4.08E+09

Average Btu/ton

1.31E+04

Outputs from Facility

None

Facility Description

Facility operates 1 shift/day. Incinerator residuals are compacted and covered on a daily basis.

Energy Use

Diesel fuel is used in mobile equipment; electricity is for pump stations and scales.

Assumptions

Energy demand based on annual use.

Sources

SCS.

APPENDIX II-D

SOLID WASTE MANAGEMENT VEHICLE DATA

TABLE II-D.1   Solid Waste Management System Vehicle Data

<u>Vehicle Type:</u>	<u>Capacity (cubic yards)</u>	<u>Gal. Fuel/ Hr. Operation (1)</u>	<u>Compaction Ratio(1) Recy/Comp/Garbage</u>
Collection Vehicles:			
Automatic EZ Pack	47	1	3/3/3
Manual Rear Loader-Dual Compact	18.75	1	3/4/4
Manual Rear Loader	31	1	3/5/5
Commercial Front Loader	40	1	3/5/5
Harbor Drift Skimmer	50	1	1
Roll on/Off Manual Truck (Med. Waste)	30	1	1
Roll on/Off Truck (C&D Waste)	40	1	1
Transfer Vehicles:			
Barge	5850	205*	na/na/2

* Gal. fuel/barge load

APPENDIX II-E

DETAILED ENERGY ANALYSIS OF SOLID WASTE MANAGEMENT

SCENARIOS A, B, C, AND D FOR NEW YORK CITY CASE STUDY

SCENARIO A

TABLE II-E.1. SCENARIO A - RESIDENTIAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btu's Per Year
Automatic EZ Pack	47.00	1	5.25	5.25							
Recyclables					7.13	302	0.96	3	291,465	11,305	1.55E+09
Garbage					25.77	302	0.96	3	1,053,445	40,858	5.60E+09
Manual Rear Loader	25.00	1	5.25	5.25							
Compostables: Leaf and Yardwaste					245.16	36	0.10	2.9	63,987	46,335	6.35E+09
Garbage					738.15	302	1.17	4	26,081,792	1,170,337	1.60E+11
Manual Rear Loader-Dual Compact	18.75	1	5.25	5.25							
Recyclables					350.32	302	1.50	3	8,926,592	555,432	7.61E+10
					Total Trucks	1366.53	Totals		36,417,280	1,824,267	2.50E+11
Total Energy Use by Waste Type:											
Recyclables:	7.76E+10										
Compostables	6.35E+09										
Garbage:	1.66E+11										
TOTAL ENERGY	2.50E+11										

TABLE II-E.2. SCENARIO A - COMMERCIAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btu's Per Year
Manual Rear Loader	31.00	1	5.25	5.25							
Recyclables					84.13	302	1.31	3	3,095,366	133,388	1.83E+10
Compostables					90.80	302	0.84	5	3,570,292	143,963	1.97E+10
Garbage					488.35	302	1.17	5	26,745,806	774,279	1.06E+11
Commercial Front Loader	40.00	1	5.25	5.25							
Recyclables					208.10	302	1.09	4	10,960,377	329,943	4.52E+10
Total Trucks					871.38			Totals	44,371,842	1,381,573	1.89E+11
Total Energy Use by Waste Type:											
Recyclables:	6.35E+10										
Compostables	1.97E+10										
Garbage:	1.06E+11										
TOTAL ENERGY	1.89E+11										

TABLE II-E.3. SCENARIO A - INSTITUTIONAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btu's Per Year	
Comp-Base Case Vehicle	23.97	4	5.25	21								
Recyclables					81.28	302	1.60	3	2,824,229	515,478	7.06E + 10	
Compostables					7.02	302	3.50	4	711,443	44,521	6.10E + 09	
Garbage					164.35	302	1.10	4	5,234,767	1,042,308	1.43E + 11	
					Total Trucks	252.65			Totals	8,770,439	1,602,306	2.20E + 11
Total Energy Use by Waste Type:												
Recyclables:	7.06E + 10											
Compostables	6.10E + 09											
Garbage:	1.43E + 11											
TOTAL ENERGY	2.20E + 11											

TABLE II-E.4. SCENARIO A - SPECIAL WASTE COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btu's Per Year
Automatic EZ Pack Medical Waste	47.00	1	5.25	5.25	10.68	302	1.00	3	454,776	16,933	2.32E+09
Harbor Drift Skimmer Harbor Debris	50.00	1	5.25	5.25	2.85	302	1.00	1	43,035	4,519	6.19E+08
Roll on/off Manual Truck Medical Waste	30.00	1	5.25	5.25	40.78	302	1.00	1	369,467	64,657	8.86E+09
Roll on/off Truck Construction and Demolition	40.00	1	5.25	5.25	622.42	302	1.10	1	8,270,717	986,847	1.35E+11
Total Trucks					676.73	Totals			9,137,995	1,072,955	1.47E+11
Total Energy Use by Waste Type:											
Medical Waste	1.12E+10										
Harbor Debris	6.19E+08										
Construction and Demolition	1.35E+11										
TOTAL ENERGY	1.47E+11										

TABLE II-E.5. SCENARIO A - FACILITY ENERGY

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total BTU Per Facility	Ave. BTU per Ton In	Total BTU Used in Scenario
Marine Transfer Station	2,000	604,000	2.44	1473760	1.56E+06	0.00E+00	0.00E+00	1.33E+05	7.37E+03	0.00E+00	1.42E+10	2.35E+04	0.00E+00
Incinerator Ash		0											3.46E+10
MWC-bound waste		1,473,490											0.00E+00
Landfill-bound waste		0											0.00E+00
Commercial Waste Proc w/Tran	1,500	468,000	4.06	1900080	2.13E+07	0.00E+00	0.00E+00	7.93E+04	7.93E+04	1.41E+05	6.23E+10	1.33E+05	5.81E+10
Recyclables		435,839											0.00E+00
Compostables		0											1.95E+11
MWC-bound waste		1,463,477											0.00E+00
Landfill-bound waste		0											0.00E+00
Sludge Compost	25	9,125	0.92	8395	5.46E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.73E+04	7.08E+10	7.76E+06	6.50E+10
Compostables		7,951											0.00E+00
Residues		418											0.00E+00
Sludge Compost	50	18,250	2.76	50370	3.15E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.43E+05	1.37E+11	7.50E+06	3.76E+11
Compostables		47,704											0.00E+00
Residues		2,512											0.00E+00
Sludge Compost	100	78,000	0.75	58500	1.69E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E+05	2.71E+11	3.47E+06	2.03E+11
Compostables		55,657											0.00E+00
Residues		2,929											0.00E+00
Sludge Pelletizer	150	54,750	0.92	50370	1.90E+07	0.00E+00	1.19E+09	0.00E+00	0.00E+00	0.00E+00	1.57E+12	2.87E+07	1.44E+12
Compostables		47,706											0.00E+00
Residues		2,511											0.00E+00
In-Vessel Compost (Source Sep Org)	1,500	547,500	1.12	613200	2.45E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E+05	2.44E+11	4.46E+05	2.55E+11
Compostables		532,060											0.00E+00
Residues		40,123											1.70E+10
Compostables(Med Waste)		35,384											0.00E+00
Residues(Med Waste)		2,663											0.00E+00

TABLE II-E.5. SCENARIO A - FACILITY ENERGY

(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total BTU Per Facility	Ave. BTU per Ton In	Total BTU Used in Scenario
Leaf & Yard Compost	NA	20,000	0.6	12000	5.62E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.47E+04	2.69E+10	1.34E+06	
Compostables		11,295											1.62E+10
Residues		791											0.00E+00
Sludge Chemical Stabilization	115	41,975	0.92	38617	2.08E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E+05	5.60E+10	1.33E+06	
Sludge		25024											4.40E+10
Residues		13475											0.00E+00
Commercial Paper Processing	500	151,000	6.3	951300	2.38E+07	0.00E+00	2.56E+07	0.00E+00	0.00E+00	6.28E+04	4.53E+10	3.00E+05	
Recyclables		673228											2.87E+11
Residues		284112											8.52E+10
Harbor Debris Processing	150	39,000	0.58	22620	3.15E+04	0.00E+00	0.00E+00	1.05E+04	0.00E+00	1.23E+04	5.82E+09	1.49E+05	
Recyclables		848											3.39E+09
Residues		21874											0.00E+00
MRF	500	151,000	8.4	1268400	2.54E+07	0.00E+00	1.21E+07	0.00E+00	0.00E+00	2.54E+05	3.60E+10	2.38E+05	
Recyclables		1,041,986											3.01E+11
Residues		221,823											0.00E+00
MRF (Med Waste)	500	151,000	0.24	36240	7.25E+05	0.00E+00	3.45E+05	0.00E+00	0.00E+00	7.25E+03	3.60E+10	2.38E+05	
Recyclables		27,458											8.34E+09
Residues		7,581											0.00E+00
C & D Debris Processing(C&D)	500	156,000	16.1	2511600	1.07E+06	0.00E+00	0.00E+00	2.03E+05	0.00E+00	3.52E+05	5.33E+09	3.42E+04	
Recyclables		1,246,246											8.52E+10
Residues		1,248,492											0.00E+00
Mixed Waste Processing	1,500	468,000	6.19	2896920	6.19E+07	0.00E+00	0.00E+00	1.21E+05	1.21E+05	6.19E+04	1.09E+11	2.33E+05	
Recyclables		302,184											7.03E+10
Compostables		0											0.00E+00
MWC-bound waste		2,594,996											6.04E+11
Landfill-bound waste		0											0.00E+00

TABLE II-E.5. SCENARIO A - FACILITY ENERGY

(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total BTU Per Facility	Ave. BTU per Ton In	Total BTU Used in Scenario
Dredge Spoils Dewatering	262	95,400	0.32	30528	4.87E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E+03	1.20E+09	1.26E+04	
Sludge Residues		29,805											3.74E+08
		0											0.00E+00
MWC - Mass Burn	1,000	310,250	2.5	775625	6.35E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.67E+11	8.59E+05	
Actual Annual Throughput		772,502											6.66E+11
MWC - Mass Burn	2,250	698,063	1.67	1165764	9.61E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.04E+11	8.65E+05	
Actual Annual Throughput		1,131,056											1.01E+12
MWC - Mass Burn(Med Waste)	2,250	698,063	0.16	111690	1.75E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E+11	1.64E+05	
Actual Annual Throughput		111,380											1.83E+10
MWC - Mass Burn(Harbor)	2,250	698,063	0.04	27923	8.89E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.33E+12	3.34E+06	
Actual Annual Throughput		21,874											9.33E+10
MWC - Mass Burn (BNY)	3,000	930,750	1	930750	7.31E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.67E+11	8.24E+05	
Actual Annual Throughput		930,750											7.67E+11
MWC - Mass Burn	3,000	930,750	0.75	698063	5.68E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.95E+11	8.54E+05	
Actual Annual Throughput		691,438											5.96E+11
Regional Pathological Incinerator	8	2442	0.51	1245	2.05E+05	0.00E+00	8.72E+06	0.00E+00	0.00E+00	0.00E+00	2.22E+10	9.08E+06	
Actual Annual Throughput		1231											1.12E+10
Regional Medical Waste Incinerator	330	100188	0.4	40075	2.45E+06	0.00E+00	3.05E+07	0.00E+00	0.00E+00	0.00E+00	1.44E+11	1.44E+06	
Actual Annual Throughput		39540											5.70E+10
Medical: On-Site Incinerator	5.4	1971	3.65	7194	4.26E+05	0.00E+00	4.38E+06	0.00E+00	2.45E+04	0.00E+00	3.36E+09	1.70E+06	
Actual Annual Throughput		7194											1.23E+10

TABLE II-E.5. SCENARIO A - FACILITY ENERGY

(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total BTU Per Facility	Ave. BTU per Ton In	Total BTU Used in Scenario
Codisposal Landfill	5,000	1510000	1.53	2310300	5.04E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.96E+11	1.51E+10	9.99E+03	
Sludge		21844											2.18E+08
Garbage		1018410											1.02E+10
C&D		1248492											1.25E+10
Harbor Drift		727											7.26E+06
Medical Waste		10244											1.02E+08
Ash Landfill	1,000	312000	1.73	539760	2.02E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+10	4.08E+09	1.31E+04	
MWC Ash		513,780											6.72E+09
Med Waste Incinerator Ash		23,450											3.07E+08
Harbor Debris Incinerator Ash		585											7.65E+06

Energy Recovery:

Electricity TABLE II-E.6. SCENARIO A - ENERGY GENERATION

	Combustible Tons/yr	Total Btu/lb Waste	% Elec.	Gross Heat Rate Btu/kWh	Gross kWh	Internal Energy Requirement	Internal Energy Use (kWh)	Net Kwh	Convert kWh to Btu	Total Btu/Yr Fm. Elec.
MWC - RDF 1000 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - RDF 2250 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - RDF 3000 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - Mass Burn 1000 Tons per day	772502	5147	100%	15,035	5.29E+08	12.0%	6.35E+07	4.65E+08	10,500	5.55E+12
MWC - Mass Burn(Harbor) 2250 Tons per day	21874	5000	100%	15,035	1.45E+07	12.0%	1.75E+06	1.28E+07	10,500	1.53E+11
MWC - Mass Burn(Med Waste) 2250 Tons per day	111380	5000	100%	15,035	7.41E+07	12.0%	8.89E+06	6.52E+07	10,500	7.78E+11
MWC - Mass Burn 2250 Tons per day	1131056	5320	100%	15,035	8.00E+08	12.0%	9.61E+07	7.04E+08	10,500	8.40E+12
MWC - Mass Burn(BNY) 3000 Tons per day	930750	4919	0%	15,035	0.00E+00	12.0%	7.31E+07	0.00E+00	10,500	0.00E+00
MWC - Mass Burn 3000 Tons per day	691438	5146	100%	15,035	4.73E+08	12.0%	5.68E+07	4.17E+08	10,500	4.97E+12
Sludge Incinerator	0	5000	0%	15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
Modular Incinerator	0	5000	0%	18,000	0.00E+00	13.0%	0.00E+00	0.00E+00	10,500	0.00E+00

Steam TABLE II-E.6. SCENARIO A - ENERGY GENERATION
(Continued)

	Combustible Tons/yr	Total Btu/lb Waste	% Steam	Stm. Boiler Eff.	Btu/lb Stm. Out	Steam Produced lb/yr	Convert Lb Stm to Btu	Total Btu/Yr Fm. Stm.
MWC - RDF 1000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - RDF 2250 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - RDF 3000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 1000 Tons per day	772502	5147	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(Harbor) 2250 Tons per day	21874	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(Med Waste) 2250 Tons per day	111380	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 2250 Tons per day	1131056	5320	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(BNY) 3000 Tons per day	930750	4919	100%	75.00%	1,350	5.09E+09	1,350	6.87E+12
MWC - Mass Burn 3000 Tons per day	691438	5146	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
Sludge Incinerator	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
Modular Incinerator	0	5000	0%	70.00%	1,350	0.00E+00	1,350	0.00E+00

Energy Recovery:

Landfill Gas TABLE II-E.6. SCENARIO A - ENERGY GENERATION
(Continued)

	Waste To LF Tons/yr	Meth. Gas Cf/lb	Total Gas Cf /year	Capt. Eff. at LF	Fraction LF cell w/ Gas Wells	Gas Captured Cf/year	Conv. Factor Cf to Btu	Total Btu of gas
Codisposal Landfill(Sludge & Garbage)	1,040,254	2.8	5.83E+09	0.65	1.00	3.79E+09	500	1.89E+12
Codisposal Landfill(Med Waste)	10,244	2.8	5.74E+07	0.65	1.00	3.73E+07	500	1.86E+10

	% High Btu gas	Btu Upgrade Efficiency	Total Btu to high value gas	Conv. Factor Btu/Cf HV gas	Total Cf of HV gas	Total Btus HV Gas
High Value Gas from Landfill Gas	100%	0.98	1.86E+12	980	1.89E+09	1.86E+12
High Value Gas from Landfill Gas	100%	0.98	1.83E+10	980	1.86E+07	1.83E+10

TABLE II-E.7. SCENARIO A - FACILITY ENERGY SUMMARY

Scenario A: Summary of Facility Energy Use

Waste Type	Tons	Average Process Energy Per Ton	Process Energy For Each Waste Type	Average Energy Generated Per Ton	Generated Energy For Each Waste Type	Average Disposal Energy Per Ton	Disposal Energy For Each Waste Type	Total Facility Energy By Waste Type
Recyclables	2,453,237	2.92E+05	7.16E+11					7.16E+11
Compostables	543,355	5.00E+05	2.72E+11					2.72E+11
Combustibles	3,525,746	8.94E+05	3.15E+12	7.32E+06	2.58E+13			-2.26E+13
Landfill	1,018,410			1.78E+06	1.82E+12	9.99E+03	1.02E+10	-1.81E+12
Ash Landfill	513,780						6.72E+09	6.72E+09
Bulk Recycling	182,665							
Subtotal	8,242,434							
Sludge	205,886	1.04E+07	2.13E+12	1.89E+05	3.90E+10	1.02E-04	2.18E+08	2.09E+12
Harbor Dredge	29,805	1.26E+04	3.74E+08					3.74E+08
Harbor Debris	23,449	9.26E+05	2.17E+10	6.51E+06	1.53E+11	6.86E-04	1.49E+07	-1.31E+11
Medical Waste	232,431	8.57E+05	1.99E+11	3.43E+06	7.96E+11	2.05E-03	4.09E+08	-5.97E+11
Const & Demo.	2,494,738	3.42E+04	8.52E+10			1.46E-01	1.25E+10	9.77E+10
Dredge Export	2,602,261							
Subtotal	5,593,320							
Totals	13,835,754		6.58E+12		2.86E+13		3.00E+10	-2.20E+13

TABLE II-E.8. SCENARIO A - TRANSFER ENERGY

Scenario A: Transport of Materials and Residues Between Facilities

Assumptions:

Transfer Days Per Year	302 Days
Average Truck MPG:	6 Miles/Gallon
Average Barge Gallons per Trip	205 Gallons/Trip
Diesel Fuel	138,700 Btu/Gallon

Transfer Energy
by Waste Type

	Transfer (cy)	Transfer Btus
Conventional Waste		
Recyclables	9,190,380	4.18E + 10
Compostables	86,390	3.93E + 08
Combustibles	2,968,060	1.35E + 10
Subtotal	12,244,830	5.56E + 10
Special Waste		
Sludge	53,000	2.41E + 08
Harbor Dredge	63,600	2.89E + 08
Harbor Debris	53,000	2.41E + 08
Medical Waste	68,900	3.13E + 08
Construction and Demolition	2,544,050	1.16E + 10
Subtotal	2,782,550	1.26E + 10
Totals	15,027,380	6.83E + 10

	Waste Transferred/ Year (cy)	Truck Transfer Miles/Year	Barge Trips/Year	Truck Gallons Consumed	Barge Gallons Consumed	Total Transfer Btus
Total Transport Energy	15,027,380	955,830	1,625	159,305	333,076	6.83E + 10
Rec/Comp/Comb. Trans. Energy	12,244,830	778,843	1,324	129,807	271,402	5.56E + 10
Special Transport Energy	2,782,550	176,987	301	29,498	61,674	1.26E + 10

TABLE II-E.9. SCENARIO A - ENERGY SUMMARY

Waste Stream	Number of Tons	Collection	Processing	Energy Generation	Transport	Total Disposal	Total Energy	Energy Average Btu/Ton
Recyclables	2,453,237	1.59E+11	7.16E+11		4.18E+10		9.17E+11	3.74E+05
Compostables	543,355	2.76E+10	2.72E+11		3.93E+08		3.00E+11	5.51E+05
Combustibles	3,525,746	2.39E+11	3.15E+12	2.58E+13	1.35E+10		-2.24E+13	-6.35E+06
Landfill	1,018,410	6.90E+10		1.82E+12		1.02E+10	-1.74E+12	-1.71E+06
Ash Landfill	513,780					6.72E+09	6.72E+09	1.31E+04
Bulk Recycling	182,665							
Export	5,241							
Subtotal	8,242,434							
Sludge	205,886		2.13E+12	3.90E+10	2.41E+08	2.18E+08	2.09E+12	1.02E+07
Harbor Dredge	29,805		3.74E+08		2.89E+08		6.63E+08	2.23E+04
Harbor Debris	23,449	2.48E+09	2.17E+10	1.53E+11	2.41E+08	1.49E+07	-1.28E+11	-5.47E+06
Medical Waste	232,431	4.47E+10	1.99E+11	7.96E+11	3.13E+08	4.09E+08	-5.52E+11	-2.37E+06
Construction & Demolition	2,494,738	5.41E+11	8.52E+10		1.16E+10	1.25E+10	6.50E+11	2.61E+05
Dredge Export [1]	2,602,261							
Harbor Debris Export [1]	4,750							
Subtotal	5,593,320							
MSW Subtotal		4.94E+11	4.14E+12	2.76E+13	5.56E+10	1.69E+10	-2.29E+13	Btus
Special Waste Subtotal		5.88E+11	2.44E+12	9.88E+11	1.26E+10	1.31E+10	2.06E+12	Btus
Totals	13,835,754	1.08E+12	6.58E+12	2.86E+13	6.83E+10	3.00E+10	-2.08E+13	Btus

[1] These wastes are part of the New York City generated waste stream. However, they are managed outside New York City, and thus no energy values appear for these waste components.

SCENARIO B

TABLE II-E.10. SCENARIO B - RESIDENTIAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year
Automatic EZ Pack	47.00	1	5.25	5.25							
Recyclables					7.13	302	0.96	3	291,465	11,305	1.55E+09
Compostables					32.26	302	0.11	3	151,106	51,148	7.01E+09
Garbage					24.21	302	0.87	3	896,892	38,385	5.26E+09
Manual Rear Loader-Dual Compact	18.75	1	5.25	5.25							
Recyclables					350.32	302	1.50	3	8,926,592	555,432	7.61E+10
Compostables/Garbage					884.73	302	1.00	4	20,039,135	1,402,739	1.92E+11
Total Trucks					1298.7			Totals	30,305,190	2,059,010	2.82E+11
Total Energy Use by Waste Type:											
Recyclables:	7.76E+10										
Compostables	6.08E+10										
Garbage:	1.44E+11										
TOTAL ENERGY	2.82E+11										

TABLE II-E.11. SCENARIO B - COMMERCIAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year
Manual Rear Loader	31.00	1	5.25	5.25							
Recyclables					84.13	302	1.31	3	3,095,366	133,388	1.83E + 10
Compostables					90.80	302	0.84	5	3,570,292	143,963	1.97E + 10
Garbage					488.35	302	1.17	5	26,745,806	774,279	1.06E + 11
Commercial Front Loader	40.00	1	5.25	5.25							
Recyclables					208.10	302	1.09	4	10,960,377	329,943	4.52E + 10
					Total Trucks	871.38	Totals		44,371,842	1,381,573	1.89E + 11
Total Energy Use by Waste Type:											
Recyclables:	6.35E + 10										
Compostables	1.97E + 10										
Garbage:	1.06E + 11										
TOTAL ENERGY	1.89E + 11										

TABLE II-E.12. SCENARIO B - INSTITUTIONAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year	
Comp-Base Case Vehicle	23.97	1	5.25	5.25								
Recyclables					82.91	302	1.21	3	2,178,655	131,454	1.80E + 10	
Compostables					7.02	302	4.00	4	813,078	11,130	1.52E + 09	
Garbage					164.35	302	1.09	4	5,187,178	260,577	3.57E + 10	
					Total Trucks	254.28			Totals	8,178,911	403,161	5.52E + 10
Total Energy Use by Waste Type:												
Recyclables:	1.80E + 10											
Compostables	1.52E + 09											
Garbage:	3.57E + 10											
TOTAL ENERGY												
5.52E + 10												

TABLE II-E.13. SCENARIO B - SPECIAL WASTE COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year
Automatic EZ Pack Medical Waste	47.00	1	5.25	5.25	10.68	302	1.00	3	454,776	16,933	2.32E+09
Harbor Drift Skimmer Harbor Debris	50.00	1	5.25	5.25	2.85	302	1.00	1	43,035	4,519	6.19E+08
Roll on/off Manual Truck Medical Waste	30.00	1	5.25	5.25	40.78	302	1.00	1	369,467	64,657	8.86E+09
Roll on/off Truck Construction and Demolition	40.00	1	5.25	5.25	622.42	302	1.10	1	8,270,717	986,847	1.35E+11
				Total Trucks	676.73			Totals	9,137,995	1,072,955	1.47E+11
Total Energy Use by Waste Type:											
Harbor Debris	6.19E+08										
Medical Waste	1.12E+10										
Construction and Demolition	1.35E+11										
TOTAL ENERGY	1.47E+11										

TABLE II-E.14. SCENARIO B - FACILITY ENERGY

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Marine Transfer Station	2,000	604,000	2.89	1745560	1.85E+06	0.00E+00	0.00E+00	1.57E+05	8.73E+03	0.00E+00	1.42E+10	2.35E+04	
In-Vessel Compost bound		803,974											1.89E+10
Incinerator Ash		0											0.00E+00
MWC-bound waste		941,523											2.21E+10
Landfill-bound waste		0											0.00E+00
Commercial Waste Proc w/Tran	1,500	468,000	4.07	1904760	2.13E+07	0.00E+00	0.00E+00	7.95E+04	7.95E+04	1.41E+05	6.23E+10	1.33E+05	
Recyclables		437,194											5.82E+10
Compostables		0											0.00E+00
MWC-bound waste		1,467,363											1.95E+11
Landfill-bound waste		0											0.00E+00
Sludge Compost	25	9,125	0.92	8395	5.46E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.73E+04	7.08E+10	7.76E+06	
Compostables		7,951											6.50E+10
Residues		418											0.00E+00
Sludge Compost	50	18,250	2.76	50370	3.15E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.43E+05	1.37E+11	7.50E+06	
Compostables		47,704											3.76E+11
Residues		2,512											0.00E+00
Sludge Compost	100	78,000	0.75	58500	1.69E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E+05	2.71E+11	3.47E+06	
Compostables		55,657											2.03E+11
Residues		2,929											0.00E+00
Sludge Pelletizer	150	54,750	0.92	50370	1.90E+07	0.00E+00	1.19E+09	0.00E+00	0.00E+00	0.00E+00	1.57E+12	2.87E+07	
Compostables		47,706											1.44E+12
Residues		2,511											0.00E+00
In-Vessel Compost (Source Sep Org)	1,500	547,500	2.29	1253775	5.02E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.41E+05	2.44E+11	4.46E+05	
Compostables		1,127,518											5.41E+11
Residues		84,867											0.00E+00
Compostables(Med Waste)		35,384											1.70E+10
Residues(Med Waste)		2,663											0.00E+00

TABLE II-E.14. SCENARIO B - FACILITY ENERGY
(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Sludge Chemical Stabilization	115	41,975	0.92	38617	2.08E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E+05	5.60E+10	1.33E+06	
Sludge		25,024											4.40E+10
Residues		13,475											0.00E+00
Commercial Paper Processing	500	151,000	6.3	951300	2.38E+07	0.00E+00	2.56E+07	0.00E+00	0.00E+00	6.28E+04	4.53E+10	3.00E+05	
Recyclables		673,228											2.87E+11
Residues		284,112											8.52E+10
Harbor Debris Processing	150	39,000	0.58	22620	3.15E+04	0.00E+00	0.00E+00	1.05E+04	0.00E+00	1.23E+04	5.82E+09	1.49E+05	
Recyclables		848											3.39E+09
Residues		21,874											0.00E+00
MRF	500	151,000	8.4	1268400	2.54E+07	0.00E+00	1.21E+07	0.00E+00	0.00E+00	2.54E+05	3.60E+10	2.38E+05	
Recyclables		1,042,146											3.01E+11
Residues		221,823											0.00E+00
MRF (Med Waste)	500	151,000	0.24	36240	7.25E+05	0.00E+00	3.45E+05	0.00E+00	0.00E+00	7.25E+03	3.60E+10	2.38E+05	
Recyclables		27,458											8.34E+09
Residues		7,581											0.00E+00
C & D Debris Processing(C&D)	500	156,000	16	2496000	1.06E+06	0.00E+00	0.00E+00	2.02E+05	0.00E+00	3.49E+05	5.33E+09	3.42E+04	
Recyclables		1,246,246											8.52E+10
Residues		1,248,492											0.00E+00
Mixed Waste Processing	1,500	468,000	5.32	2489760	5.32E+07	0.00E+00	0.00E+00	1.04E+05	1.04E+05	5.32E+04	1.09E+11	2.33E+05	
Recyclables		328,417											7.64E+10
Compostables		0											0.00E+00
MWC-bound waste		2,160,326											5.03E+11
Landfill-bound waste		0											0.00E+00

TABLE II-E.14. SCENARIO B - FACILITY ENERGY
(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Dredge Spoils Dewatering	262	95,400	0.32	30528	4.87E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E+03	1.20E+09	1.26E+04	
Sludge		29,805											3.74E+08
Residues		0											0.00E+00
MWC - Mass Burn	1,000	310,250	2.36	732190	6.61E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.94E+11	9.48E+05	
Actual Annual Throughput		731,402											6.94E+11
MWC - Mass Burn	2,250	698,063	1.06	739946	6.60E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.54E+11	9.37E+05	
Actual Annual Throughput		735,176											6.93E+11
MWC - Mass Burn(Med Waste)	2,250	698,063	0.16	111690	8.89E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.83E+11	8.36E+05	
Actual Annual Throughput		111,380											9.33E+10
MWC - Mass Burn(Harbor)	2,250	698,063	0.04	27923	1.75E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E+11	6.57E+05	
Actual Annual Throughput		21,874											1.83E+10
MWC - Mass Burn (BNY)	3,000	930,750	1	930750	7.68E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.06E+11	8.66E+05	
Actual Annual Throughput		930,750											8.06E+11
MWC - Mass Burn	3,000	930,750	0.75	698063	5.83E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.17E+11	8.78E+05	
Actual Annual Throughput		693,478											6.13E+11
Regional Pathological Incinerator	8	2,442	0.51	1245	2.05E+05	0.00E+00	8.72E+06	0.00E+00	0.00E+00	0.00E+00	2.22E+10	9.08E+06	
Actual Annual Throughput		1,231											1.12E+10
Regional Medical Waste Incinerator	330	100,188	0.4	40075	2.45E+06	0.00E+00	3.05E+07	0.00E+00	0.00E+00	0.00E+00	1.44E+11	1.44E+06	
Actual Annual Throughput		39,540											5.70E+10
Medical: On-Site Incinerator	5.4	1,971	3.65	7194	4.26E+05	0.00E+00	4.38E+06	0.00E+00	2.45E+04	0.00E+00	3,36E+09	1.70E+06	
Actual Annual Throughput		7,194											1.23E+10

TABLE II-E.14. SCENARIO B - FACILITY ENERGY
(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Codisposal Landfill	5,000	1,510,000	1.41	2129100	4.64E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E+11	1.51E+10	9.99E+03	
Sludge		21,844											2.18E+08
Garbage		846,778											8.46E+09
C&D		1,248,492											1.25E+10
Harbor Drift		727											7.26E+06
Medical Waste		10,244											1.02E+08
Ash Landfill	1,000	312,000	1.65	514800	1.92E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+10	4.08E+09	1.31E+04	
MWC Ash		490,699											6.41E+09
Med Waste Incinerator Ash		23,450											3.07E+08
Harbor Debris Incinerator Ash		585											7.65E+06

Energy Recovery:

Electricity

TABLE II-E.15. SCENARIO B - ENERGY GENERATION

	Incin Tons/yr	Total Btu/lb Waste	% Elec.	Gross Heat Rate Btu/kWh	Gross kWh	Internal Energy Requirement	Internal Energy Use (kWh)	Net Kwh	Convert kWh to Btu	Total Btu/Yr Fm. Elec.
MWC - RDF 1000 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - RDF 2250 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - RDF 3000 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - Mass Burn 1000 Tons per day	731402	5661	100%	15,035	5.51E+08	12.0%	6.61E+07	4.85E+08	10,500	5.78E+12
MWC - Mass Burn(Harbor) 2250 Tons per day	21874	5000	100%	15,035	1.45E+07	12.0%	1.75E+06	1.28E+07	10,500	1.53E+11
MWC - Mass Burn(Med Waste) 2250 Tons per day	111380	5000	100%	15,035	7.41E+07	12.0%	8.89E+06	6.52E+07	10,500	7.78E+11
MWC - Mass Burn 2250 Tons per day	735176	5627	100%	15,035	5.50E+08	12.0%	6.60E+07	4.84E+08	10,500	5.78E+12
MWC - Mass Burn(BNY) 3000 Tons per day	930750	5169	0%	15,035	0.00E+00	12.0%	7.68E+07	0.00E+00	10,500	0.00E+00
MWC - Mass Burn 3000 Tons per day	693478	5271	100%	15,035	4.86E+08	12.0%	5.83E+07	4.28E+08	10,500	5.11E+12
Sludge Incinerator	0	5000	0%	15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
Modular Incinerator	0	5000	0%	18,000	0.00E+00	13.0%	0.00E+00	0.00E+00	10,500	0.00E+00

Energy Recovery:

Steam

TABLE II-E.15. SCENARIO B - ENERGY GENERATION
(Continued)

	Incin Tons/yr	Total Btu/lb Waste	% Steam	Stm. Boiler Eff.	Btu/lb Stm. Out	Steam Produced lb/yr	Convert Lb Stm to Btu	Total Btu/Yr Fm. Stm.
MWC - RDF 1000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - RDF 2250 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - RDF 3000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 1000 Tons per day	731402	5661	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(Harbor) 2250 Tons per day	21874	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(Med Waste) 2250 Tons per day	111380	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 2250 Tons per day	735176	5627	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(BNY) 3000 Tons per day	930750	5169	100%	75.00%	1,350	5.35E+09	1,350	7.22E+12
MWC - Mass Burn 3000 Tons per day	693478	5271	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
Sludge Incinerator	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
Modular Incinerator	0	5000	0%	70.00%	1,350	0.00E+00	1,350	0.00E+00

Energy Recovery:

Landfill Gas

TABLE II-E.15. SCENARIO B - ENERGY GENERATION
(Continued)

	Waste To LF Tons/yr	Meth. Gas Cf/lb	Total Gas Cf /year	Capt. Eff. at LF	Fraction LF cell w/ Gas Wells	Gas Captured Cf/year	Conv. Factor Cf to Btu	Total Btu of gas
disposal Landfill(Sludge & Garbage)	868,622	2.8	4.86E+09	0.65	1.00	3.16E+09	500	1.58E+12
Codisposal Landfill(Med Waste)	10,244	2.8	5.74E+07	0.65	1.00	3.73E+07	500	1.86E+10

	% High Btu gas	Btu Upgrade Efficiency	Total Btu to high value gas	Conv. Factor Btu/Cf HV gas	Total cf of HV gas	Total Btus HV Gas
High Value Gas from Landfill Gas	100%	0.98	1.55E+12	980	1.58E+09	1.55E+12
High Value Gas from Landfill Gas	100%	0.98	1.83E+10	980	1.86E+07	1.83E+10

TABLE II-E.16. SCENARIO B - FACILITY ENERGY SUMMARY

Scenario B: Summary of Facility Energy Use

Waste Type	Tons	Average Process Energy Per Ton	Process Energy For Each Waste Type	Average Energy Generated Per Ton	Generated Energy For Each Waste Type	Average Disposal Energy Per Ton	Disposal Energy For Each Waste Type	Total Facility Energy By Waste Type
Recyclables	2,480,985	2.91E+05	7.23E+11					7.23E+11
Compostables	1,127,518	4.97E+05	5.60E+11					5.60E+11
Combustibles	3,090,806	9.44E+05	2.92E+12	7.73E+06	2.39E+13			-2.10E+13
Landfill	846,778			1.78E+06	1.51E+12	9.99E+03	8.46E+09	-1.50E+12
Ash Landfill	490,699					1.31E+04	6.41E+09	6.41E+09
Bulk Recycling	182,665							
Subtotal	8,219,451							
Sludge	205,886	1.04E+07	2.13E+12	1.89E+05	3.90E+10	1.02E-04	2.18E+08	2.09E+12
Harbor Dredge	29,805	1.26E+04	3.74E+08					3.74E+08
Harbor Debris	23,449	9.26E+05	2.17E+10	6.51E+06	1.53E+11	6.86E-04	1.49E+07	-1.31E+11
Medical Waste	232,431	8.57E+05	1.99E+11	3.43E+06	7.96E+11	2.05E-03	4.09E+08	-5.97E+11
Const & Demo.	2,494,738	3.42E+04	8.52E+10			1.46E-01	1.25E+10	9.77E+10
Dredge Export	2,602,261							
Harbor Debris Export	4,750							
Subtotal	5,593,320							
Totals	13,812,771		6.64E+12		2.64E+13		2.80E+10	-1.97E+13

TABLE II-E.17. SCENARIO B - TRANSFER ENERGY

Scenario B: Transport of Materials and Residues Between Facilities

Assumptions:

Transfer Days Per Year	302 Days
Average Truck MPG:	6 Miles/Gallon
Average Barge Gallons per Trip	205 Gallons/Trip
Diesel Fuel	138,700 Btu/Gallon

Transfer Energy by

Waste Type	Transfer (cy)	Transfer Btus
Conventional Waste		
Recyclables	8,395,360	3.48E + 10
Compostables	1,812,630	7.51E + 09
Combustibles	2,968,060	1.23E + 10
Subtotal	13,176,050	5.46E + 10
Special Waste		
Sludge	53,000	2.41E + 08
Harbor Dredge	63,600	2.89E + 08
Harbor Debris	53,000	2.41E + 08
Medical Waste	68,900	3.13E + 08
Construction and Demolition	2,544,050	1.16E + 10
Subtotal	2,782,550	1.26E + 10
Totals	15,958,600	6.72E + 10

	Waste Transferred/ Year (cy)	Truck Transfer Miles/Year	Barge Trips/Year	Truck Gallons Consumed	Barge Gallons Consumed	Total Transfer Btus
Total Transport Energy	15,958,600	835,240	1,685	139,207	345,458	6.72E + 10
Rec/Comp/Comb. Trans. Energy	13,176,050	658,253	1,384	109,709	283,784	5.46E + 10
Special Transport Energy	2,782,550	176,987	301	29,498	61,674	1.26E + 10

NOTE: VALUES FOR SPECIAL ASSUME SAME TRANSPORT MILES AS SCENARIO A
THESE ARE THEN SUBTRACTED TO DETERMINE TOTAL CONV. TRANS ENERGY

TABLE II-E.18. SCENARIO B - ENERGY SUMMARY.

Waste Stream	Number of Tons	Collection	Processing	Energy Generation	Transport	Total Disposal	Total Energy	Energy Average Btu/Ton
Recyclables	2,480,985	1.59E+11	7.23E+11		3.48E+10		9.17E+11	3.69E+05
Compostables	1,127,518	8.21E+10	5.60E+11		7.51E+09		6.50E+11	5.76E+05
Combustibles	3,090,806	2.24E+11	2.92E+12	2.39E+13	1.23E+10		-2.07E+13	-6.71E+06
Landfill	846,778	6.14E+10		1.51E+12		8.46E+09	-1.44E+12	-1.70E+06
Ash Landfill	490,699					6.41E+09	6.41E+09	1.31E+04
Bulk Recycling Export	182,665							
Subtotal	8,219,451							
Sludge	205,886		2.13E+12	3.90E+10	2.41E+08	2.18E+08	2.09E+12	1.02E+07
Harbor Dredge	29,805		3.74E+08		2.89E+08		6.63E+08	2.23E+04
Harbor Debris	23,449	2.48E+09	2.17E+10	1.53E+11	2.41E+08	1.49E+07	-1.28E+11	-5.47E+06
Medical Waste	232,431	4.47E+10	1.99E+11	7.96E+11	3.13E+08	4.09E+08	-5.52E+11	-2.37E+06
Construction & Demolition	2,494,738	5.41E+11	8.52E+10		1.16E+10	1.25E+10	6.50E+11	2.61E+05
Dredge Export [1]	2,602,261							
Harbor Debris Export [1]	4,750							
Subtotal	5,593,320							
MSW Subtotal		5.27E+11	4.20E+12	2.54E+13	5.46E+10	1.49E+10	-2.06E+13	Btus
Special Waste Subtotal		5.88E+11	2.44E+12	9.88E+11	1.26E+10	1.31E+10	2.06E+12	Btus
Totals	13,812,771	1.11E+12	6.64E+12	2.64E+13	6.72E+10	2.80E+10	-1.85E+13	Btus

[1] These wastes are part of the New York City generated waste stream. However, they are managed outside New York City, and thus no energy values appear for these waste components.

SCENARIO C

TABLE II-E.19. SCENARIO C - RESIDENTIAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year
Automatic EZ Pack	47.00	1	5.25	5.25							
Recyclables					7.13	302	0.96	3	291,465	11,305	1.55E + 09
Compostables					32.26	302	0.11	3	151,106	51,148	7.01E + 09
Garbage					24.21	302	0.87	3	896,892	38,385	5.26E + 09
Manual Rear Loader-Dual Compact	18.75	1	5.25	5.25							
Recyclables					350.32	302	1.50	3	8,926,592	555,432	7.61E + 10
Compostables/Garbage					884.73	302	1.00	4	20,039,135	1,402,739	1.92E + 11
					Total Trucks	1298.7	Totals		30,305,190	2,059,010	2.82E + 11
Total Energy Use by Waste Type:											
Recyclables:	7.76E + 10										
Compostables	6.08E + 10										
Garbage:	1.44E + 11										
TOTAL ENERGY	2.82E + 11										

TABLE II-E.20. SCENARIO C - COMMERCIAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year
Manual Rear Loader	31.00	1	5.25	5.25							
Recyclables					84.13	302	1.31	3	3,095,366	133,388	1.83E + 10
Compostables					90.80	302	0.84	5	3,570,292	143,963	1.97E + 10
Garbage					488.35	302	1.17	5	26,745,806	774,279	1.06E + 11
Commercial Front Loader	40.00	1	5.25	5.25							
Recyclables					208.10	302	1.09	4	10,960,377	329,943	4.52E + 10
Total Trucks					871.38			Totals	44,371,842	1,381,573	1.89E + 11
Total Energy Use by Waste Type:											
Recyclables:	6.35E + 10										
Compostables	1.97E + 10										
Garbage:	1.06E + 11										
TOTAL ENERGY	1.89E + 11										

TABLE II-E.21. SCENARIO C - INSTITUTIONAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year	
Comp-Base Case Vehicle	23.97	1	5.25	5.25								
Recyclables					82.91	302	1.21	3	2,178,655	131,454	1.80E + 10	
Compostables					7.02	302	4.00	4	813,078	11,130	1.52E + 09	
Garbage					164.35	302	1.09	4	5,187,178	260,577	3.57E + 10	
				Total Trucks	<u>254.28</u>				Totals	<u>8,178,911</u>	<u>403,161</u>	<u>5.52E + 10</u>
<u>Total Energy Use by Waste Type:</u>												
Recyclables:	1.80E + 10											
Compostables	1.52E + 09											
Garbage:	<u>3.57E + 10</u>											
TOTAL ENERGY	<u>5.52E + 10</u>											

TABLE II-E.22. SCENARIO C - SPECIAL WASTE COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year
Automatic EZ Pack Medical Waste	47.00	1	5.25	5.25	10.68	302	1.00	3	454,776	16,933	2.32E+09
Harbor Drift Skimmer Harbor Debris	50.00	1	5.25	5.25	2.85	302	1.00	1	43,035	4,519	6.19E+08
Roll on/off Manual Truck Medical Waste	30.00	1	5.25	5.25	40.78	302	1.00	1	369,467	64,657	8.86E+09
Roll on/off Truck Construction and Demolition	40.00	1	5.25	5.25	622.42	302	1.10	1	8,270,717	986,847	1.35E+11
Total Trucks					676.73	Totals			9,137,995	1,072,955	1.47E+11
Total Energy Use by Waste Type:											
Harbor Debris	6.19E+08										
Medical Waste	1.12E+10										
Construction and Demolition	1.35E+11										
TOTAL ENERGY	1.47E+11										

TABLE II-E.23. SCENARIO C - FACILITY ENERGY

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Marine Transfer Station	2,000	604,000	2.18	1316720	1.40E+06	0.00E+00	0.00E+00	1.19E+05	6.58E+03	0.00E+00	1.42E+10	2.35E+04	
In-Vessel Compost bound		803,974											1.89E+10
Incinerator Ash		0											0.00E+00
Mixed WP -bound waste		511,605											1.20E+10
MWC-bound waste		0											0.00E+00
Landfill-bound waste		0											0.00E+00
Commercial Waste Proc w/Tran	1,500	468,000	4.07	1904760	2.13E+07	0.00E+00	0.00E+00	7.95E+04	7.95E+04	1.41E+05	6.23E+10	1.33E+05	
Recyclables		436,076											5.81E+10
Mixed WP - bound waste		1,464,401											1.95E+11
MWC-bound waste		0											0.00E+00
Landfill-bound waste		0											0.00E+00
Sludge Compost	25	9,125	0.92	8395	5.46E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.73E+04	7.08E+10	7.76E+06	
Compostables		7,951											6.50E+10
Residues		418											0.00E+00
Sludge Compost	50	18,250	2.76	50370	3.15E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.43E+05	1.37E+11	7.50E+06	
Compostables		47,704											3.76E+11
Residues		2,512											0.00E+00
Sludge Compost	100	78,000	0.75	58500	1.69E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E+05	2.71E+11	3.47E+06	
Compostables		55,657											2.03E+11
Residues		2,929											0.00E+00
Sludge Pelletizer	150	54,750	0.92	50370	1.90E+07	0.00E+00	1.19E+09	0.00E+00	0.00E+00	0.00E+00	1.57E+12	2.87E+07	
Compostables		47,706											1.44E+12
Residues		2,511											0.00E+00
In-Vessel Compost (Source Sep Org)	1,500	547,500	2.29	1253775	5.02E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.41E+05	2.44E+11	4.46E+05	
Compostables		1,127,518											5.41E+11
Residues		84,867											0.00E+00
Compostables(Med Waste)		35,384											1.70E+10
Residues(Med Waste)		2,663											0.00E+00

TABLE II-E.23. SCENARIO C - FACILITY ENERGY
(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Sludge Chemical Stabilization	115	41,975	0.92	38617	2.08E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E+05	5.60E+10	1.33E+06	
Sludge		25,024											4.40E+10
Residues		13,475											0.00E+00
Commercial Paper Processing	500	151,000	6.3	951300	2.38E+07	0.00E+00	2.56E+07	0.00E+00	0.00E+00	6.28E+04	4.53E+10	3.00E+05	
Recyclables		673,228											2.87E+11
Residues		284,112											8.52E+10
Harbor Debris Processing	150	39,000	0.58	22620	3.15E+04	0.00E+00	0.00E+00	1.05E+04	0.00E+00	1.23E+04	5.82E+09	1.49E+05	
Recyclables		848											3.39E+09
Residues		21,874											0.00E+00
MRF	500	151,000	8.4	1268400	2.54E+07	0.00E+00	1.21E+07	0.00E+00	0.00E+00	2.54E+05	3.60E+10	2.38E+05	
Recyclables		1,042,146											3.01E+11
Residues		221,823											0.00E+00
MRF (Med Waste)	500	151,000	0.24	36240	7.25E+05	0.00E+00	3.45E+05	0.00E+00	0.00E+00	7.25E+03	3.60E+10	2.38E+05	
Recyclables		27,458											8.34E+09
Residues		7,581											0.00E+00
C & D Debris Processing(C&D))	500	156,000	16.1	2511600	1.07E+06	0.00E+00	0.00E+00	2.03E+05	0.00E+00	3.52E+05	5.33E+09	3.42E+04	
Recyclables		1,246,246											8.52E+10
Residues		1,248,492											0.00E+00
Mixed Waste Processing	1,500	468,000	7.83	3664440	7.83E+07	0.00E+00	0.00E+00	1.53E+05	1.53E+05	7.83E+04	1.09E+11	2.33E+05	
Recyclables		368,208											8.57E+10
Compostables		1,846,980											4.30E+11
MWC-bound waste		0											0.00E+00
Landfill-bound waste		1,445,908											3.36E+11

TABLE II-E.23. SCENARIO C - FACILITY ENERGY
(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Dredge Spoils Dewatering	262	95,400	0.32	30528	4.87E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E+03	1.20E+09	1.26E+04	
Sludge		29,805											3.74E+08
Residues		0											0.00E+00
MWC - Mass Burn(Med Waste)	2,250	698,063	0.16	111690	8.89E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.83E+11	8.36E+05	
Actual Annual Throughput		111,380											9.33E+10
MWC - Mass Burn(Harbor)	2,250	698,063	0.04	27923	1.75E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E+11	6.57E+05	
Actual Annual Throughput		21,874											1.83E+10
Regional Pathological Incinerator	8	2,442	0.51	1245	2.05E+05	0.00E+00	8.72E+06	0.00E+00	0.00E+00	0.00E+00	2.22E+10	9.08E+06	
Actual Annual Throughput		1,231											1.12E+10
Regional Medical Waste Incinerator	330	100,188	0.4	40075	2.45E+06	0.00E+00	3.05E+07	0.00E+00	0.00E+00	0.00E+00	1.44E+11	1.44E+06	
Actual Annual Throughput		39,540											5.70E+10
Medical: On-Site Incinerator	5.4	1,971	3.65	7194	4.26E+05	0.00E+00	4.38E+06	0.00E+00	2.45E+04	0.00E+00	3.36E+09	1.70E+06	
Actual Annual Throughput		7,194											1.23E+10
Codisposal Landfill	5,000	1,510,000	2.3	3473000	7.57E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.95E+11	1.51E+10	9.99E+03	
Sludge		21,844											2.18E+08
Garbage		2,048,121											2.05E+10
C&D		1,248,492											1.25E+10
Harbor Drift		727											7.26E+06
Medical Waste		10,244											1.02E+08
Ash Landfill	1,000	312,000	0.08	24960	9.33E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E+08	4.08E+09	1.31E+04	
MWC Ash		0											0.00E+00
Med Waste Incinerator Ash		23,450											3.07E+08
Harbor Debris Incinerator Ash		585											7.65E+06

Energy Recovery:

Electricity

TABLE II-E.24. SCENARIO C - ENERGY GENERATION

Rate	Incin Tons/yr	Total Btu/lb Waste	% Elec.	Gross Heat Btu/kWh	Gross kWh	Internal Energy Requirement	Internal Energy Use (kWh)	Net kWh	Convert kWh to Btu	Total Btu/Yr Fm. Elec.
MWC - RDF 1000 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - RDF 2250 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - RDF 3000 Tons per day	0	5000	0%	15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - Mass Burn 1000 Tons per day	0	5000	0%	15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - Mass Burn(Harbor) 2250 Tons per day	21874	5000	100%	15,035	1.45E+07	12.0%	1.75E+06	1.28E+07	10,500	1.53E+11
MWC - Mass Burn(Med Waste) 2250 Tons per day	111380	5000	100%	15,035	7.41E+07	12.0%	8.89E+06	6.52E+07	10,500	7.78E+11
MWC - Mass Burn 2250 Tons per day	0	5000	0%	15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - Mass Burn(BNY) 3000 Tons per day	0	5000	0%	15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - Mass Burn 3000 Tons per day	0	5000	0%	15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
Sludge Incinerator	0	5000	0%	15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
Modular Incinerator	0	5000	0%	18,000	0.00E+00	13.0%	0.00E+00	0.00E+00	10,500	0.00E+00

Energy Recovery:

Steam

TABLE II-E.24. SCENARIO C - ENERGY GENERATION
(Continued)

	Incin Tons/yr	Total Btu/lb Waste	% Steam	Stm. Boiler Eff.	Btu/lb Stm. Out	Steam Produced lb/yr	Convert Lb Stm to Btu	Total Btu/Yr Fm. Stm.
MWC - RDF 1000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - RDF 2250 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - RDF 3000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 1000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(Harbor) 2250 Tons per day	21874	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(Med Waste) 2250 Tons per day	111380	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 2250 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(BNY) 3000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 3000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
Sludge Incinerator	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
Modular Incinerator	0	5000	0%	70.00%	1,350	0.00E+00	1,350	0.00E+00

Energy Recovery:

Landfill Gas

TABLE II-E.24. SCENARIO C - ENERGY GENERATION
(Continued)

	Waste To LF Tons/yr	Meth. Gas Cf/lb	Total Gas Cf /year	Capt. Eff. at LF	Fraction LF cell w/ Gas Wells	Gas Captured Cf/year	Conv. Factor Cf to Btu	Total Btu of gas
Codisposal Landfill(Sludge & Garbage)	2,069,965	2.8	1.16E+10	0.65	1.00	7.53E+09	500	3.77E+12
Codisposal Landfill(Med Waste)	10,244	2.8	5.74E+07	0.65	1.00	3.73E+07	500	1.86E+10

	% High Btu gas	Btu Upgrade Efficiency	Total Btu to high value gas	Conv. Factor Btu/Cf HV gas	Total Cf of HV gas	Total Btus HV Gas
High Value Gas from Landfill Gas	100%	0.98	3.69E+12	980	3.77E+09	3.69E+12
High Value Gas from Landfill Gas	100%	0.98	1.83E+10	980	1.86E+07	1.83E+10

TABLE II-E.25. SCENARIO C - FACILITY ENERGY SUMMARY

Scenario C: Summary of Facility Energy Use

Waste Type	Tons	Average Process Energy Per Ton	Process Energy For Each Waste Type	Average Energy Generated Per Ton	Generated Energy For Each Waste Type	Average Disposal Energy Per Ton	Disposal Energy For Each Waste Type	Total Facility Energy By Waste Type
Recyclables	2,519,658	2.90E+05	7.32E+11					7.32E+11
Compostables	2,974,498	4.02E+05	1.20E+12					1.20E+12
Combustibles								
Landfill	2,048,121	1.64E+05	3.36E+11	1.78E+06	3.65E+12	9.99E+03	2.05E+10	-3.30E+12
Ash Landfill								
Bulk Recycling	182,665							
Export	4,081							
Subtotal	7,729,023							
Sludge	205,886	1.04E+07	2.13E+12	1.89E+05	3.90E+10	1.02E-04	2.18E+08	2.13E+12
Harbor Dredge	29,805	1.26E+04	3.74E+08					3.74E+08
Harbor Debris	23,449	9.26E+05	2.17E+10	6.51E+06	1.53E+11	6.86E-04	1.49E+07	2.17E+10
Medical Waste	232,431	8.57E+05	1.99E+11	3.43E+06	7.96E+11	2.05E-03	4.09E+08	2.00E+11
Const & Demo.	2,494,738	3.42E+04	8.52E+10			1.46E-01	1.25E+10	9.77E+10
Dredge Export	2,602,261							
Harbor Debris Export	4,750							
Subtotal	5,593,320							
Totals	13,322,343		4.70E+12		4.64E+12		3.36E+10	1.08E+12

TABLE II-E.26. SCENARIO C - TRANSFER ENERGY

Scenario C: Transport of Materials and Residues Between Facilities

Assumptions:

Transfer Days Per Year	302 Days
Average Truck MPG:	6 Miles/Gallon
Average Barge Gallons per Trip	205 Gallons/Trip
Diesel Fuel	138,700 Btu/Gallon

Transfer Energy by Waste Type	Transfer (cy)	Transfer Btus
Conventional Waste		
Recyclables	3,996,280	3.91E+10
Compostables	2,872,650	2.81E+10
Combustibles	0	0.00E+00
Subtotal	6,868,930	6.73E+10
Special Waste		
Sludge	53,000	2.41E+08
Harbor Dredge	63,600	2.89E+08
Harbor Debris	53,000	2.41E+08
Medical Waste	68,900	3.13E+08
Construction and Demolition	2,544,050	1.16E+10
Subtotal	2,782,550	1.26E+10
Totals	9,651,480	7.99E+10

	Waste Transferred/ Year (cy)	Truck Transfer Miles/Year	Barge Trips/Year	Truck Gallons Consumed	Barge Gallons Consumed	Total Transfer BTUs
Total Transport Energy	9,651,480	406,794	2,479	67,799	508,281	7.99E+10
Rec/Comp/Comb. Trans. Energy	6,868,930	229,807	2,179	38,301	446,607	6.73E+10
Special Transport Energy	2,782,550	176,987	301	29,498	61,674	1.26E+10

NOTE: VALUES FOR SPECIAL ASSUME SAME TRANSPORT MILES AS SCENARIO A
THESE ARE THEN SUBTRACTED TO DETERMINE TOTAL CONV. TRANS ENERGY

TABLE II-E.27. SCENARIO C - ENERGY SUMMARY

Waste Stream	Number of Tons	Collection	Processing	Energy Generation	Transport	Total Disposal	Total Energy	Energy Average Btu/Ton
Recyclables	2,519,658	1.59E+11	7.32E+11		3.91E+10		9.30E+11	3.69E+05
Compostables	2,974,498	8.21E+10	1.20E+12		2.81E+10		1.31E+12	4.39E+05
Combustibles								
Landfill	2,048,121	2.85E+11	3.36E+11	3.65E+12		2.05E+10	-3.01E+12	-1.47E+06
Ash Landfill								
Bulk Recycling	182,665							
Export	4,081							
Subtotal	7,729,023							
Sludge	205,886		2.13E+12	3.90E+10	2.41E+08	2.18E+08	2.09E+12	1.02E+07
Harbor Dredge	29,805		3.74E+08		2.89E+08		6.63E+08	2.23E+04
Harbor Debris	23,449	2.48E+09	2.17E+10	1.53E+11	2.41E+08	1.49E+07	-1.28E+11	-5.47E+06
Medical Waste	232,431	4.47E+10	1.99E+11	7.96E+11	3.13E+08	4.09E+08	-5.52E+11	-2.37E+06
Construction & Demolition	2,494,738	5.41E+11	8.52E+10		1.16E+10	1.25E+10	6.50E+11	2.61E+05
Dredge Export [1]	2,602,261							
Harbor Debris Export [1]	4,750							
Subtotal	5,593,320							
MSW Subtotal		5.27E+11	2.27E+12	3.65E+12	6.73E+10	2.05E+10	-7.74E+11	Btus
Special Waste Subtotal		5.88E+11	2.44E+12	9.88E+11	1.26E+10	1.31E+10	2.06E+12	Btus
Totals	13,322,343	1.11E+12	4.70E+12	4.64E+12	7.99E+10	3.36E+10	1.29E+12	Btus

[1] These wastes are part of the New York City generated waste stream. However, they are managed outside New York City, and thus no energy values appear for these waste components.

SCENARIO D

TABLE II-E.28. SCENARIO D - RESIDENTIAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year	
Automatic EZ Pack Garbage	47.00	1	5.25	5.25	28.63	302	1.11	3	1,353,226	45,393	6.22E + 09	
Manual Rear Loader Garbage	25.00	1	5.25	5.25	964.38	302	1.21	4	35,240,374	1,529,024	2.09E + 11	
					Total Trucks	993.01			Totals	36,593,600	1,574,417	2.16E + 11
Total Energy Use by Waste Type:												
Recyclables:												
Compostables												
Garbage:												
										2.16E + 11		
TOTAL ENERGY										2.16E + 11		

TABLE II-E.29. SCENARIO D - COMMERCIAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year
Manual Rear Loader	31.00	1	5.25	5.25							
Recyclables					95.27	302	1.25	3	3,344,692	151,051	2.07E + 10
Garbage					600.69	302	1.08	5	30,367,763	952,394	1.30E + 11
Commercial Front Loader	40.00	1	5.25	5.25							
Recyclables					199.70	302	1.11	4	10,710,949	316,624	4.34E + 10
					Total Trucks	895.66	Totals		44,423,404	1,420,069	1.95E + 11
Total Energy Use by Waste Type:											
Recyclables:	6.41E + 10										
Compostables											
Garbage:	1.30E + 11										
TOTAL ENERGY	1.95E + 11										

TABLE II-E.30. SCENARIO D - INSTITUTIONAL COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year	
Comp-Base Case Vehicle Garbage	23.97	1	5.25	5.25	284.33	302	1.07	4	8,809,301	450,805	6.18E + 10	
				Total Trucks	<u>284.33</u>				Totals	<u>8,809,301</u>	<u>450,805</u>	<u>6.18E + 10</u>
<u>Total Energy Use by Waste Type:</u>												
Recyclables:												
Compostables												
Garbage:												
										<u>6.18E + 10</u>		
TOTAL ENERGY										<u>6.18E + 10</u>		

TABLE II-E.31. SCENARIO D - SPECIAL WASTE COLLECTION

Vehicle Name	Vehicle Capacity in cubic yards	Gallons of Fuel per Hour	Daily Hours of Operation	Total Fuel Use Per Day	Number of Trucks of Trucks	Number of Collection Days per Year	Loads Per Truck Per Day	Compaction of Truck X:1	Total Cubic Yards Collected	Total Annual Fuel Use	Total Btus Per Year
Automatic EZ Pack Medical Waste	47.00	1	5.25	5.25	10.68	302	1.00	3	454,776	16,933	2.32E+09
Harbor Drift Skimmer Harbor Debris	50.00	1	5.25	5.25	2.85	302	1.00	1	43,035	4,519	6.19E+08
Roll on/off Manual Truck Medical Waste	30.00	1	5.25	5.25	40.78	302	1.00	1	369,467	64,657	8.86E+09
Roll on/off Truck Construction and Demolition	40.00	1	5.25	5.25	622.42	302	1.10	1	8,270,717	986,847	1.35E+11
Total Trucks					676.73	Totals			9,137,995	1,072,955	1.47E+11
Total Energy Use by Waste Type:											
Harbor Debris	6.19E+08										
Medical Waste	1.12E+10										
Construction and Demolition	1.35E+11										
TOTAL ENERGY	1.47E+11										

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TABLE II-E.32. SCENARIO D - FACILITY ENERGY

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Marine Transfer Station	2,000	604,000	3.52	2126080	2.25E+06	0.00E+00	0.00E+00	1.91E+05	1.06E+04	0.00E+00	1.42E+10	2.35E+04	
In-Vessel Compost bound		0											0.00E+00
Incinerator Ash		0											0.00E+00
MWC-bound waste		2,124,632											4.99E+10
Landfill-bound waste		0											0.00E+00
Commercial Waste Proc w/Tran	1,500	468,000	4.93	2307240	2.58E+07	0.00E+00	0.00E+00	9.63E+04	9.63E+04	1.71E+05	6.23E+10	1.33E+05	
Recyclables		446,556											5.95E+10
Compostables		0											0.00E+00
MWC-bound waste		1,859,957											2.48E+11
Landfill-bound waste		0											0.00E+00
Sludge Compost	25	9,125	0.92	8395	5.46E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.73E+04	7.08E+10	7.76E+06	
Compostables		7,951											6.50E+10
Residues		418											0.00E+00
Sludge Compost	50	18,250	2.76	50370	3.15E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.43E+05	1.37E+11	7.50E+06	
Compostables		47,704											3.76E+11
Residues		2,512											0.00E+00
Sludge Compost	100	78,000	0.75	58500	1.69E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E+05	2.71E+11	3.47E+06	
Compostables		55,657											2.03E+11
Residues		2,929											0.00E+00
Sludge Pelletizer	150	54,750	0.92	50370	1.90E+07	0.00E+00	1.19E+09	0.00E+00	0.00E+00	0.00E+00	1.57E+12	2.87E+07	
Compostables		47,706											1.44E+12
Residues		2,511											0.00E+00
In-Vessel Compost (Source Sep Org)	1,500	547,500	0.07	38325	1.53E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.36E+03	2.44E+11	4.46E+05	
Compostables		0											0.00E+00
Residues		0											0.00E+00
Compostables(Med Waste)		35,384											1.70E+10
Residues(Med Waste)		2,663											0.00E+00

TABLE II-E.32. SCENARIO D - FACILITY ENERGY

(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Sludge Chemical Stabilization	115	41,975	0.92	38617	2.08E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E+05	5.60E+10	1.33E+06	4.40E+10
Sludge		25,024											0.00E+00
Residues		13,475											
Commercial Paper Processing	500	151,000	6.3	951300	2.38E+07	0.00E+00	2.56E+07	0.00E+00	0.00E+00	6.28E+04	4.53E+10	3.00E+05	2.76E+11
Recyclables		646,096											8.18E+10
Residues		272,816											
Harbor Debris Processing	150	39,000	0.58	22620	3.15E+04	0.00E+00	0.00E+00	1.05E+04	0.00E+00	1.23E+04	5.82E+09	1.49E+05	3.39E+09
Recyclables		848											0.00E+00
Residues		21,874											
MRF	500	151,000	2.2	332200	6.64E+06	0.00E+00	3.16E+06	0.00E+00	0.00E+00	6.64E+04	3.60E+10	2.38E+05	7.89E+10
Recyclables		257,759											0.00E+00
Residues		73,611											
MRF (Med Waste)	500	151,000	0.24	36240	7.25E+05	0.00E+00	3.45E+05	0.00E+00	0.00E+00	7.25E+03	3.60E+10	2.38E+05	8.34E+09
Recyclables		27,458											0.00E+00
Residues		7,581											
C & D Debris Processing(C&D))	500	156,000	16.1	2511600	1.07E+06	0.00E+00	0.00E+00	2.03E+05	0.00E+00	3.52E+05	5.33E+09	3.42E+04	8.52E+10
Recyclables		1,246,246											0.00E+00
Residues		1,248,492											

TABLE II-E.32. SCENARIO D - FACILITY ENERGY
(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Dredge Spoils Dewatering Sludge Residues	262	95,400 29,805 0	0.32	30528	4.87E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E+03	1.20E+09	1.26E+04	3.74E+08 0.00E+00
MWC - RDF Actual Annual Throughput Recyclables	2,250	698,063 2,300,690 123,563	3.3	2303606	2.18E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.93E+11	9.92E+05	2.29E+12
MWC - RDF Actual Annual Throughput Recyclables	3,000	930,750 829,861 44,432	0.9	837675	7.35E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.57E+11	9.21E+05	7.71E+11
MWC - Mass Burn Actual Annual Throughput	1,000	310,250 930,750	3	930750	7.49E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.62E+11	8.45E+05	7.86E+11
MWC - Mass Burn(Med Waste) Actual Annual Throughput	2,250	698,063 111,380	0.16	111690	8.89E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.83E+11	8.36E+05	9.33E+10
MWC - Mass Burn(Harbor) Actual Annual Throughput	2,250	698,063 21,874	0.04	27923	1.75E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E+11	6.57E+05	1.83E+10
MWC - Mass Burn (BNY) Actual Annual Throughput	3,000	930,750 930,750	1	930750	7.64E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.02E+11	8.62E+05	8.02E+11
Regional Pathological Incinerator Actual Annual Throughput	8	2,442 1,231	0.51	1245	2.05E+05	0.00E+00	8.72E+06	0.00E+00	0.00E+00	0.00E+00	2.22E+10	9.08E+06	1.12E+10
Regional Medical Waste Incinerator Actual Annual Throughput	330	100,188 39,540	0.4	40075	2.45E+06	0.00E+00	3.05E+07	0.00E+00	0.00E+00	0.00E+00	1.44E+11	1.44E+06	5.70E+10
Medical: On-Site Incinerator Actual Annual Throughput	5.4	1,971 7,194	3.65	7194	4.26E+05	0.00E+00	4.38E+06	0.00E+00	2.45E+04	0.00E+00	3.36E+09	1.70E+06	1.23E+10

TABLE II-E.32. SCENARIO D - FACILITY ENERGY
(Continued)

Facility	Design Capacity (tons/day)	Annual Throughput (tons)	Number of Facilities	Total Tons	Total Electricity kWh	Total Propane Cf	Total Nat Gas Cf	Total Heating Oil (Gallons)	Total Gas (Gallons)	Total Diesel (Gallons)	Total Btu Per Facility	Ave. Btu per Ton In	Total Btu Used in Scenario
Codisposal Landfill	5,000	1,510,000	1.51	2280100	4.97E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.94E+11	1.51E+10	9.99E+03	
Sludge		21,844											2.18E+08
Garbage		989,156											9.88E+09
C&D		1,248,492											1.25E+10
Harbor Drift		727											7.26E+06
Medical Waste		10,244											1.02E+08
Ash Landfill	1,000	312,000	2.48	773760	2.89E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E+10	4.08E+09	1.31E+04	
MWC Ash		747,352											9.77E+09
Med Waste Incinerator Ash		23,450											3.07E+08
Harbor Debris Incinerator Ash		585											7.65E+06

Electricity TABLE II-E.33. SCENARIO D - ENERGY GENERATION
(Continued)

	Incin Tons/yr	Total Btu/lb Waste	% Elec.	Gross Heat Rate Btu/kWh	Gross kWh	Internal Energy Requirement	Internal Energy Use (kWh)	Net kWh	Convert kWh to Btu	Total Btu/Yr Fm. Elec.
MWC - RDF 1000 Tons per day	0	5000		15,035	0.00E+00	13.5%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - RDF 2250 Tons per day	2300690	5268	100%	15,035	1.61E+09	13.5%	2.18E+08	1.39E+09	10,500	1.69E+13
MWC - RDF 3000 Tons per day	829861	4930	100%	15,035	5.44E+08	13.5%	7.35E+07	4.71E+08	10,500	5.71E+12
MWC - Mass Burn 1000 Tons per day	930750	5041	100%	15,035	6.24E+08	12.0%	7.49E+07	5.49E+08	10,500	6.55E+12
MWC - Mass Burn(Harbor) 2250 Tons per day	21874	5000	100%	15,035	1.45E+07	12.0%	1.75E+06	1.28E+07	10,500	1.53E+11
MWC - Mass Burn(Med Waste) 2250 Tons per day	111380	5000	100%	15,035	7.41E+07	12.0%	8.89E+06	6.52E+07	10,500	7.78E+11
MWC - Mass Burn 2250 Tons per day	0	5000		15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
MWC - Mass Burn(BNY) 3000 Tons per day	930750	5142		15,035	0.00E+00	12.0%	7.64E+07	0.00E+00	10,500	0.00E+00
MWC - Mass Burn 3000 Tons per day	0	5000		15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
Sludge Incinerator	0	5000		15,035	0.00E+00	12.0%	0.00E+00	0.00E+00	10,500	0.00E+00
Modular Incinerator	0	5000		18,000	0.00E+00	13.0%	0.00E+00	0.00E+00	10,500	0.00E+00

Energy Recovery:

Steam TABLE II-E.33. SCENARIO D - ENERGY GENERATION
(Continued)

	Incinerator Tons/yr	Total Btu/lb Waste	% Steam	Steam Boiler Eff.	Btu/lb Steam Out	Steam Produced lb/yr	Convert Lb Steam to Btu	Total Btu/Yr From Steam
MWC - RDF 1000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - RDF 2250 Tons per day	2300690	5268	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - RDF 3000 Tons per day	829861	4930	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 1000 Tons per day	930750	5041	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(Harbor) 2250 Tons per day	21874	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(Med Waste) 2250 Tons per day	111380	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn 2250 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
MWC - Mass Burn(BNY) 3000 Tons per day	930750	5142	100%	75.00%	1,350	5.32E+09	1,350	7.18E+12
MWC - Mass Burn 3000 Tons per day	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
Sludge Incinerator	0	5000	0%	75.00%	1,350	0.00E+00	1,350	0.00E+00
Modular Incinerator	0	5000	0%	70.00%	1,350	0.00E+00	1,350	0.00E+00

Energy Recovery:

Landfill Gas TABLE II-E.33. SCENARIO D - ENERGY GENERATION
(Continued)

	Waste To LF Tons/yr	Meth. Gas Cf/lb	Total Gas Cf /year	Capt. Eff. at LF	Fraction LF cell w/ Gas Wells	Gas Captured Cf/year	Conv. Factor Cf to Btu	Total Btu of gas
Codisposal Landfill(Sludge & Garbage)	1,011,000	2.8	5.66E+09	0.65	1.00	3.68E+09	500	1.84E+12
Codisposal Landfill(Med Waste)	10,244	2.8	5.74E+07	0.65	1.00	3.73E+07	500	1.86E+10

	% High Btu gas	Btu Upgrade Efficiency	Total Btu to high value gas	Conv. Factor Btu/Cf HV gas	Total cf of HV gas	Total Btus HV Gas
High Value Gas from Landfill Gas	100%	0.98	1.80E+12	980	1.84E+09	1.80E+12
High Value Gas from Landfill Gas	100%	0.98	1.83E+10	980	1.86E+07	1.83E+10

TABLE II-E.34. SCENARIO D - FACILITY ENERGY SUMMARY

Scenario D: Summary of Facility Energy Use

Waste Type	Tons	Average Process Energy Per Ton	Process Energy For Each Waste Type	Average Energy Generated Per Ton	Generated Energy For Each Waste Type	Average Disposal Energy Per Ton	Disposal Energy For Each Waste Type	Total Facility Energy By Waste Type
Recyclables	1,518,406	2.73E+05	4.14E+11					4.14E+11
Compostables								
Combustibles	4,992,051	9.90E+05	4.94E+12	7.29E+06	3.64E+13			-3.14E+13
Landfill	989,156			1.78E+06	1.76E+12	9.99E+03	9.88E+09	-1.75E+12
Ash Landfill	747,352					1.31E+04	9.77E+09	9.77E+09
Bulk Recycling	182,665							
Export	53,658							
Subtotal	8,483,288							
Sludge	205,886	1.04E+07	2.13E+12	1.89E+05	3.90E+10	1.02E-04	2.18E+08	2.13E+12
Harbor Dredge	29,805	1.26E+04	3.74E+08					3.74E+08
Harbor Debris	23,449	9.26E+05	2.17E+10	6.51E+06	1.53E+11	6.86E-04	1.49E+07	2.17E+10
Medical Waste	232,431	8.57E+05	1.99E+11	3.43E+06	7.96E+11	2.05E-03	4.09E+08	2.00E+11
Const & Demo.	2,494,738	3.42E+04	8.52E+10			1.46E-01	1.25E+10	9.77E+10
Dredge Export	2,602,261							
Harbor Debris Export	4,750							
Subtotal	5,593,320							
Total Scenario Tons	14,076,608		7.79E+12		3.91E+13		3.28E+10	-3.03E+13

TABLE II-E.35. SCENARIO D - TRANSFER ENERGY

Scenario D: Transport of Materials and Residues Between Facilities

Assumptions:

Transfer Days Per Year	302 Days
Average Truck MPG:	6 Miles/Gallon
Average Barge Gallons per Trip	205 Gallons/Trip
Diesel Fuel	138,700 Btu/Gallon

Transfer Energy by

Waste Type	Transfer (cy)	Transfer Btus
Conventional Waste		
Recyclables	10,669,100	4.41E + 10
Compostables	0	0.00E + 00
Combustibles	5,787,710	2.39E + 10
Subtotal	16,456,810	6.80E + 10
Special Waste		
Sludge	53,000	2.41E + 08
Harbor Dredge	63,600	2.89E + 08
Harbor Debris	53,000	2.41E + 08
Medical Waste	68,900	3.13E + 08
Construction and Demolition	2,544,050	1.16E + 10
Subtotal	2,782,550	1.26E + 10
Totals	19,239,360	8.06E + 10

	Waste Transferred/ Year (cy)	Truck Transfer Miles/Year	Barge Trips/Year	Truck Gallons Consumed	Barge Gallons Consumed	Total Transfer Btus
Total Transport Energy	19,239,360	1,400,509	1,697	233,418	347,934	8.06E + 10
Rec/Comp/Comb. Trans. Energy	16,456,810	1,223,522	1,396	203,920	286,260	6.80E + 10
Special Transport Energy	2,782,550	176,987	301	29,498	61,674	1.26E + 10

TABLE II-E.36. SCENARIO D - ENERGY SUMMARY

Waste Stream	Number of Tons	Collection	Processing	Energy Generation	Transport	Total Disposal	Total Energy	Energy Average Btu/Ton
Recyclables	1,518,406	6.41E+10	4.14E+11		4.41E+10		5.22E+11	3.44E+05
Compostables								
Combustibles	4,992,051	3.40E+11	4.94E+12	3.64E+13	2.39E+10		-3.11E+13	-6.22E+06
Landfill	989,156	6.75E+10		1.76E+12		9.88E+09	-1.69E+12	-1.71E+06
Ash Landfill	747,352					9.77E+09	9.77E+09	1.31E+04
Bulk Recycling	182,665							
Export	53,658							
Subtotal	8,483,288							
Sludge	205,886		2.13E+12	3.90E+10	2.41E+08	2.18E+08	2.09E+12	1.02E+07
Harbor Dredge	29,805		3.74E+08		2.89E+08		6.63E+08	2.23E+04
Harbor Debris	23,449	2.48E+09	2.17E+10	1.53E+11	2.41E+08	1.49E+07	-1.28E+11	-5.47E+06
Medical Waste	232,431	4.47E+10	1.99E+11	7.96E+11	3.13E+08	4.09E+08	-5.52E+11	-2.37E+06
Construction & Demolition	2,494,738	5.41E+11	8.52E+10		1.16E+10	1.25E+10	6.50E+11	2.61E+05
Dredge Export	2,602,261							
Harbor Debris Export	4,750							
Subtotal	5,593,320							
MSW Subtotal		4.72E+11	5.36E+12	3.81E+13	6.80E+10	1.97E+10	-3.22E+13	Btus
Special Waste Subtotal		5.88E+11	2.44E+12	9.88E+11	1.26E+10	1.31E+10	2.06E+12	Btus
Totals	14,076,608	1.06E+12	7.79E+12	3.91E+13	8.06E+10	3.28E+10	-3.02E+13	Btus

[1] These wastes are part of the New York City generated waste stream. However, they are managed outside New York City, and thus no energy values appear for these waste components.

APPENDIX III-A
MANUFACTURING SYSTEM FLOW DIAGRAMS
AND
MATERIAL AND ENERGY TABLES

Figure III-A.1
KRAFT PULP PRODUCTION

TABLE III-A.1

MATERIAL AND ENERGY INPUTS: KRAFT PULP PRODUCTION

PROCESS				
	Material Input		Units/ton	MMBtu
	Process Energy	Units	BDT pulp	Equivalents/ BDT pulp
ROUNDWOOD HARVESTING [1]				
	Whole Trees (48% water) [2]	pounds	7328	
	Gasoline	gallons	2	0.26 [7]
	Diesel	gallons	1	0.18 [7]
WOOD CONVEYANCE, DEBARKING, CHIPPING and SCREENING				
	Roundwood (48% water)	pounds	6106	
	Forest Residues (48% water)	pounds	473	
	Electricity	kWh	4	0.04 [3]
	Diesel	gallons	0.23	0.03 [3]
WHITE LIQUOR (Pulping Liquor) PREPARATION				
	Sodium sulfate (from various ind. wastes)	pounds	131	[7]
	Lime (calcium oxide)	pounds	31	[7]
	Steam	pounds	89	0.13 [6]
	Electricity	kWh	11	0.11 [5]
DIGESTION [4]				
	Wood Chips from roundwood (bone dry)		2698	
	Wood Chips from forest residues (bone dry)		209	
	Manu. Residues (bone dry)		1538	
	White liquor		7911	
	Steam		1321	1.85 [6]
WEAK BLACK LIQUOR EVAPORATION				
	Steam	pounds	2429	3.40 [6,8]
BLACK LIQUOR RECOVERY				
	Heat input and losses - Steam	pounds	2500	3.50 [6,8]
LIME REBURNING				
	Oil	gallons	10	1.50 [6,8]
PUMPING, SCREENING and WASHING				
	Steam	pounds	410	0.57 [3]
	Electricity	kWh	64	0.67 [3]
				12.24

KRAFT PULP PRODUCTION - TOTAL ENERGY USE

Fuels:

Gasoline	gallons	2	0.26
Diesel	gallons	2	0.21
Oil	gallons	10	1.50
Steam	pounds	6749	9.45
Electricity	kWh	78	0.82

Total MMBtu/BDT Kraft Pulp

12.24

Breakdown of Energy Sources - Residue and Purchased:

Energy Recovery from Process Wastes	19.50 [6]
Purchased Energy:	-7.26 [6]

TABLE III-A.1 (CONTINUED)

MATERIAL AND ENERGY INPUTS: KRAFT PULP PRODUCTION

Notes:

- [1] Harry L. Brown. "Energy Analysis of 108 Industrial Processes". 1985.
- [2] Origin of wood fiber based on API's "Paper Paperboard Wood Pulp Capacity", 1988-1991:
  - Roundwood, and roundwood chips- 60.7%
  - Forest residues (logging residues) - 4.7%
  - Manufacturing residues (sawdust, planer shavings, and mill broke) - 34.6%
- [3] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.
- [4] Based on a 45% pulping yield.
- [5] A. D. Little. "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume V. Pulp and Paper Industry Report", 1976.
- [6] Personal communication with R.T. Campbell, International Paper, March 1992.
- [7] M. Sittig. "Pulp and Paper Manufacture", 1977.
- [8] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).

Figure III-A.2

VIRGIN LINERBOARD PRODUCTION

TABLE III-A.2

MATERIAL AND ENERGY INPUTS: VIRGIN LINERBOARD FORMING AND DRYING

PROCESS			MMBtu	
Material Input		Units/ton	Equivalents/	
Process Energy		linerboard	ton linerboard	
FURNISH REFINING, ADDITIVES MIXING, FINAL CLEANING, AND TEMP. ADJUSTMENT				
Unbleached Kraft Pulp	pounds	1783		
Resin	pounds	8		
Alum	pounds	12		
Starch	pounds	18		
Steam	pounds	429		0.60 [1]
Electricity	kWh	64		0.67 [1]
FORMING, PRESSING, DRYING, CALENDERING, AND WINDING (FOURDRINIER MACHINE)				
Stock (bone dry)	pounds	1821		
Steam	pounds	7857		11.00 [2]
Electricity	kWh	104		1.09 [2]
				13.36
LINERBOARD PRODUCTION - TOTAL ENERGY USE				
Steam	pounds	8286		11.60
Electricity	kWh	168		1.76
Total MMBtu/ton Linerboard				13.36

Notes:

[1] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.

[2] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).

TABLE III-A-3

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN LINERBOARD PRODUCTION

PROCESS			
Material Output		Units /ton	MMBtu
Process/Transportation Energy	Units	linerboard	Equivalents/ton linerboard
KRAFT PULPING			
Pulp (bone dry)	pounds	1783	
Fuels:			
Gasoline	gallons	2	0.23
Diesel	gallons	1	0.19
Oil	gallons	9	1.34
Steam	pounds	6017	8.42
Electricity	kWh	69	0.73
Transportation-Diesel [1]	gallons	7	0.91
LINERBOARD PRODUCTION			
Linerboard	pounds	2000	
Steam	pounds	8286	11.60
Electricity	kWh	168	1.76
			<u>25.19</u>

VIRGIN LINERBOARD PRODUCTION - TOTAL ENERGY USE

Fuels:			
Gasoline	gallons	2	0.23
Diesel	gallons	1	0.19
Oil	gallons	9	1.34
Steam	pounds	14303	20.02
Electricity	kWh	237	2.49
Transportation-Diesel [1]	gallons	7	<u>0.91</u>
Total MMBtu/Ton Virgin Linerboard			25.19

Breakdown of Process Energy Sources - Residue and Purchased:

Residue: Energy from by-product combustion from Kraft pulping	17.38
Purchased	7.80

Notes:

[1] Transportation of roundwood, forest and manufacturing residues to mill by truck - average travel distance estimated at 100 miles.

Figure III-A.3

RECYCLED LINERBOARD PRODUCTION

TABLE III-A.4

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED LINERBOARD PRODUCTION

PROCESS			MMBtu
Material Input		Units/ton	Equivalents/
Process Energy	Units	linerboard [1]	ton linerboard
WASTEPAPER PULPING			
OCC/kraft paper	pounds	2300 [2]	
Electricity	kWh	397	4.17 [4]
Transportation - Diesel [5]	gallons	10	1.44 [5]
FURNISH REFINING, ADDITIVES MIXING, FINAL CLEANING, AND TEMP. ADJUSTMENT			
Pulp (bone dry)	pounds	1839 [1]	
Rosin	pounds	30	
Alum	pounds	50	
Starch	pounds	18	
Steam	pounds	429	0.60 [3]
Electricity	kWh	59	0.62 [3]
FORMING, PRESSING, DRYING, CALENDERING, AND WINDING			
Stock (bone dry)	pounds	1937 [1]	
Steam	pounds	9714	13.60 [4]
Electricity	kWh	168	1.76 [4]
			22.18

RECYCLED LINERBOARD PRODUCTION - TOTAL ENERGY USE			
Steam	pounds	10143	14.20
Electricity	kWh	623	6.54
Transportation - Diesel [5]	gallons	10	1.44
			22.18
Total MMBtu/ton Recycled Linerboard			22.18

Notes:

- [1] M. Sittig. "Pulp and Paper Manufacture". 1977.
- [2] Based on 15% of wastepaper removed as contaminants, in pulping and cleaning (figure given for planned linerboard mill in "Solid Waste Report," April 20, 1992).
- [3] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.
- [4] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).
- [5] Transportation of waste paper by truck - average travel distance 500 miles.

Figure III-A.4

KRAFT PULP BLEACHING

TABLE III-A.5

MATERIAL AND ENERGY INPUTS: KRAFT PULP BLEACHING (CEoD)

PROCESS				MMBtu
Material Input		Units/ton		Equivalents/
Process Energy	Units	BDT BL		ton BL
BLEACHING				
Unbleached Pulp (bone dry)	pounds	2117 [1]		
Chlorine	pounds	74 [1]		
Chlorine dioxide	pounds	35 [2]		
Caustic (sodium hydroxide)	pounds	122 [1]		
Oxygen	pounds	not avail.		
Steam	pounds	2500	3.50 [4]	
Electricity	kWh	143	1.50 [4]	
				5.00

BLEACHED KRAFT PULP PRODUCTION - TOTAL ENERGY USE				
Fuels:				
Steam	pounds	2500	3.50	
Electricity	kWh	143	1.50	
		Total MMBtu/BDT BL Kraft Pulp	5.00	

Notes:

- [1] M. Sittig. "Pulp and Paper Manufacture". 1977.
- [2] Written communication from R.T. Campbell, International Paper, Aug. 1, 1991
- [3] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.
- [4] Personal communication with R.T. Campbell, International Paper, March 1992.

Figure III-A.5

VIRGIN NEWSPRINT PRODUCTION

(Thermomechanical-95%)

TABLE III-A.6

MATERIAL AND ENERGY INPUTS: THERMOMECHANICAL PULP (TMP) PRODUCTION

PROCESS	Material Input	Units	Units/ton BDT TMP	MMBtu Equivalents/ ton TMP
	Process Energy			
PULPWOOD HARVESTING [1]				
	Whole Trees (48% water)	pounds	3471	
	Gasoline	gallons	1	0.12 [3]
	Diesel	gallons	1	0.08 [3]
WOOD CONVEYANCE, DEBARKING, CHIPPING and SCREENING				
	Roundwood (48% water)	pounds	2893 [2]	
	Forest Residues (48% water)	pounds	224 [2]	
	Electricity		2	0.02 [3]
	Diesel		0.12	0.02 [3]
PREHEATING [4]				
	Wood Chips from roundwood (bone dry)		1278 [2]	
	Wood chips from forest residues (bone dry)		99 [2]	
	Manu. Residues (bone dry)		728 [2]	
	Steam	pounds	571	0.80 [8]
REFINING				
	Electricity	kWh	1800	18.90 [8]
PUMPING, CLEANING and SCREENING				
	Steam	pounds	410	0.57 [3]
	Electricity	kWh	64	0.67 [3]
				21.19

TMP PRODUCTION - TOTAL ENERGY USE

Fuels:				
	Gasoline	gallons	1	0.12
	Diesel	gallons	1	0.10
	Steam	pounds	982	1.37
	Electricity	kWh	1866	19.59
Total MMBtu/BDT TMP				21.19

Breakdown of Energy Sources - Residue and Purchased:

Residue: Energy Recovery from Process Wood Waste (bark, fines, etc.)	2.46 [7]
Purchased	18.73

Notes:

- [1] Harry L. Brown. "Energy Analysis of 108 Industrial Processes". 1985.
- [2] Origin of wood fiber based on API's "Paper Paperboard Wood Pulp Capacity", 1988-1991:
- Roundwood, and roundwood chips- 60.7%
  - Forest residues (logging residues) - 4.7%
  - Manufacturing residues (sawdust, planer shavings, and mill broke) - 34.6%
- (Btu value of manufacturing residues not included)
- [3] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.
- [4] Based on a 95% pulping yield.

TABLE III-A.6 (CONTINUED)

MATERIAL AND ENERGY INPUTS: THERMOMECHANICAL PULP (TMP) PRODUCTION

- [5] A. D. Little. "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume V. Pulp and Paper Industry Report", 1976.
- [6] Based on a HHV of 6900 Btu/lb from D. Wilson. "Handbook of Solid Waste Management". 1977.
- [7] M. Sittig. "Pulp and Paper Manufacture", 1977.
- [8] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).

TABLE III-A.7

MATERIAL AND ENERGY INPUTS: VIRGIN NEWSPRINT FORMING AND DRYING

PROCESS			MMBtu
Material Input		Units/ton	Equivalents/
Process Energy	Units	linerboard	ton linerboard
FURNISH REFINING, ADDITIVES MIXING, FINAL CLEANING, AND TEMP. ADJUSTMENT			
Thermomechanical Pulp (bone dry)	pounds	1841	
Semi-bleached Kraft Pulp (bone dry)	pounds	97	
Steam	pounds	429	0.60 [1]
Electricity	kWh	64	0.67 [1]
FORMING, DRYING, CALENDERING, AND WINDING (FOURDRINIER MACHINE)			
Stock (bone dry)	pounds	1938	
Steam	pounds	3571	5.00 [2]
Electricity	kWh	111	1.16 [2]
			7.43

NEWSPRINT PRODUCTION - TOTAL ENERGY USE			
Steam	pounds	4000	5.60
Electricity	kWh	175	1.83
		Total MMBtu/ton Newsprint	7.43

Notes:

[1] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.

[2] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).

TABLE III-A.8

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN NEWSPRINT PRODUCTION

PROCESS			MMBtu
Material Output		Units /ton	Equivalents/ton
Process/Transportation Energy	Units	newsprint	newsprint
KRAFT PULPING			
Pulp (bone dry)	pounds	103	
Fuels:			
Gasoline	gallons	0.11	0.01
Diesel	gallons	0.08	0.01
Oil	gallons	1	0.08
Steam	pounds	346	0.48
Electricity	kWh	4	0.04
Transportation-Diesel [1]	gallons	0.38	0.05
KRAFT PULP BLEACHING			
Bleached Pulp (bone dry)	pounds	97	
Fuels:			
Steam	pounds	121	0.17
Electricity	kWh	7	0.07
TMP PRODUCTION			
TMP (bone dry)	pounds	1841	
Fuels:			
Gasoline	gallons	1	0.11
Diesel	gallons	1	0.09
Steam	pounds	904	1.27
Electricity	kWh	1717	18.03
Transportation-Diesel [1]	gallons	3.19	0.44
NEWSPRINT PRODUCTION			
Newsprint	pounds	2000	
Steam	pounds	4000	5.60
Electricity	kWh	175	1.83
			<u>28.30</u>

VIRGIN NEWSPRINT PRODUCTION - TOTAL ENERGY USE

Fuels:			
Gasoline	gallons	1	0.13
Diesel	gallons	1	0.10
Oil	gallons	1	0.08
Steam	pounds	5371	7.52
Electricity	kWh	1903	19.98
Transportation-Diesel [1]	gallons	4	<u>0.49</u>

Total MMBtu/Ton Virgin Newsprint 28.30

Breakdown of Process Energy Sources - Residue and Purchased:

Residue: Energy from by-product combustion from Kraft pulping	1.00
Energy from by-product combustion from TMP production	2.27
Total energy from by-product combustion:	3.27
Purchased	25.04

Notes:

[1] Transportation of roundwood, forest and manufacturing residues to mill by truck - average travel distance estimated at 100 miles.

Figure III-A.6

RECYCLED NEWSPRINT PRODUCTION

TABLE III-A.9

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED NEWSPRINT PRODUCTION

PROCESS	Material Input	Units	Units/ton newsprint [1]	MMBtu Equivalents/ ton newsprint
	Process Energy			
WASTEPAPER PULPING				
	ONP	pounds	2333 [2]	
	Caustic	pounds	40	
	Electricity	kWh	397	4.17 [5]
	Transportation - Diesel [6]	gallons	12	1.73 [6]
DEINKING				
	Palp	pounds	1954	
	Steam	pounds	414	0.58 [1]
	Electricity	kWh	129	1.35 [1]
CLEANING, SCREENING, AND WASHING				
	Steam	pounds	429	0.60 [3]
	Electricity	kWh	62	0.65 [3]
FORMING, PRESSING, DRYING, CALENDERING, AND WINDING				
	Stock (bone dry)	pounds	1938 [1]	
	Steam	pounds	5357	7.50 [4]
	Electricity	kWh	67	0.70 [4]
				17.28

RECYCLED NEWSPRINT PRODUCTION - TOTAL ENERGY USE				
	Steam	pounds	6200	8.68
	Electricity	kWh	655	6.87
	Transportation - Diesel [5]	gallons	12	1.73
Total MMBtu/ton Recycled Newsprint				17.28

Notes:

[1] M. Sittig. "Pulp and Paper Manufacture". 1977.

[2] Based on 7.5% of wastepaper removed as contaminants, in pulping and cleaning.

[3] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.

[4] Arthur D. Little. "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume V. Pulp and Paper Industry Report". 1976.

[5] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).

[6] Transportation of waste paper by truck - average travel distance 750 miles.

Figure III-A.7

VIRGIN PRINTING AND WRITING PAPER PRODUCTION

TABLE III-A.10

MATERIAL AND ENERGY INPUTS: CHLORINE AND CAUSTIC PRODUCTION [1]

PROCESS			
Material Input		Units /ton	MMBtu
Process Energy	Units	chlorine	Equivalents/ton
			chlorine
BRINE PURIFICATION			
Soda ash		56	
Caustic soda		25	
Steam	pound	540	0.76
Electricity - Purchased	kWh	4	0.04
BRINE HEATING			
Steam	pound	1460	2.04
BRINE ELECTROLYSIS			
Graphite		6	
Asbestos		1	
Electricity - Purchased	kWh	2880	30.24
CHLORINE COOLING AND DRYING			
Sulfuric acid		25	
Electricity - Purchased	kWh	2	0.02
CHLORINE COMPRESSING			
Electricity - Purchased	kWh	70	0.73
CHLORINE LIQUEFYING			
Electricity - Purchased	kWh	232	2.44
CAUSTIC SODA EVAPORATION			
Dilute caustic		2240	
Steam	pound	9015	12.62
Electricity - Purchased	kWh	139	1.46
SEPARATION BY CENTRIFUGING			
Electricity - Purchased	kWh	2	0.02

TOTAL ENERGY USE - CHLORINE PRODUCTION [2]			
Fuels:			
Steam	pounds	931	1.30
Electricity - Purchased	kWh	1788	18.77
Total MMBtu/Ton Chlorine			20.08
TOTAL ENERGY USE - CAUSTIC PRODUCTION [3]			
Fuels:			
Steam	pounds	8980	12.57
Electricity - Purchased	kWh	1469	15.42
Total MMBtu/Ton Caustic			27.99

Notes:

[1] Energy values are allocated to process outputs according to the following weight output ratios:

- chlorine - 2000 lb
- caustic - 2240 lb
- hydrogen gas - 57 lb

[2] Energy for chlorine production includes a weighted fraction of steps 1-3 (according to ratios in [1]), and full energy values for steps 4-6.

[3] Energy for chlorine production includes a weighted fraction of steps 1-3 (according to ratios in [1]), and full energy values for steps 7-8.

Numbers may not add up due to rounding.

Source:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

TABLE III-A.11

MATERIAL AND ENERGY INPUTS: VIRGIN PRINTING/WRITING PAPER FORMING AND DRYING

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	office paper	Equivalents/ ton office paper
FURNISH REFINING, ADDITIVES MIXING, FINAL CLEANING, AND TEMP. ADJUSTMENT			
Bleached kraft pulp (bone dry)	pounds	1884	
Starch	pounds	15	
Filler	pounds	15	
Steam	pounds	429	0.60 [1]
Electricity	kWh	64	0.67 [1]
FORMING, DRYING, CALENDERING, AND WINDING (FOURDRINIER MACHINE)			
Stock (bone dry)	pounds	1914	
Steam	pounds	3571	5.00 [2]
Electricity	kWh	108	1.13 [2]
			7.40

PRINTING/WRITING PAPER PRODUCTION - TOTAL ENERGY USE			
Steam	pounds	4000	5.60
Electricity	kWh	172	1.80
Total MMBtu/ton Printing and Writing Paper			7.40

Notes:

[1] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.

[2] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).

TABLE III-A.12

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN PRINTING/WRITING PAPER PRODUCTION

PROCESS	Material Output	Units	Units /ton office paper	MMBtu Equivalents/ton office paper
	Process/Transportation Energy			
KRAFT PULPING				
	Pulp (bone dry)	pounds	1994	
	Fuels:			
	Gasoline	gallons	2	0.26
	Diesel	gallons	2	0.21
	Oil	gallons	10	1.50
	Steam	pounds	6729	9.42
	Electricity	kWh	78	0.82
	Transportation-Diesel [1]	gallons	7	1.02
CHLORINE PRODUCTION				
	Chlorine	pounds	70	
	Steam	pounds	32	0.05
	Electricity	kWh	62	0.66
	Transportation-Diesel [2]	gallons	0.003	0.0004
CAUSTIC PRODUCTION				
	Caustic	pounds	115	
	Steam	pounds	516	0.72
	Electricity	kWh	84	0.89
	Transportation-Diesel [2]	gallons	0.004	0.0006
KRAFT PULP BLEACHING				
	Bleached Pulp (bone dry)	pounds	1884	
	Fuels:			
	Steam	pounds	2355	3.30
	Electricity	kWh	135	1.41
PRINTING/WRITING PAPER PRODUCTION				
	Office Paper	pounds	2000	
	Steam	pounds	4000	5.60
	Electricity	kWh	172	1.80
				27.64

VIRGIN PRINTING/WRITING PAPER PRODUCTION - TOTAL ENERGY USE

Fuels:				
	Gasoline	gallons	2	0.26
	Diesel	gallons	2	0.21
	Oil	gallons	10	1.50
	Steam	pounds	13632	19.09
	Electricity	kWh	531	5.57
	Transportation-Diesel [1]	gallons	7	1.02

Total MMBtu/Ton Virgin Printing and Writing Paper 27.64

Breakdown of Process Energy Sources - Residue and Purchased:

Residue: Energy credits for by-product combustion from Kraft pulping	19.44
Purchased	8.20

Notes:

[1] Transportation of roundwood, forest and manufacturing residues to mill by truck - average travel distance estimated at 100 miles.

[2] Transportation of chlorine and caustic to mill by train - average travel distance estimated at 100 miles.

Figure III-A.8

RECYCLED PRINTING AND WRITING PAPER PRODUCTION

TABLE III-A.13

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED PRINTING/WRITING PAPER PRODUCTION

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	office paper [1]	Equivalents/ ton office paper
WASTEPAPER PULPING			
Waste Copy and Computer Paper	pounds	2283 [2]	
Caustic	pounds	40	
Electricity	kWh	381	4.00 [5]
Transportation - Diesel [6]	gallons	5	0.72 [6]
DEINKING			
Pulp	pounds	1911	
Steam	pounds	451	0.63 [1]
Electricity	kWh	140	1.47 [1]
CLEANING, SCREENING, AND WASHING			
Steam	pounds	429	0.60 [3]
Electricity	kWh	61	0.64 [3]
BLEACHING			
Pulp (bone dry)	pounds	1896 [1]	
Hypochlorite	pounds	n/a	
Steam	pounds	214	0.30
Electricity	kWh	33	0.35
FORMING, PRESSING, DRYING, CALENDERING, AND WINDING			
Stock (bone dry)	pounds	1859 [1]	
Rosin	pounds	10	
Alum	pounds	15	
Starch	pounds	15	
Fillers	pounds	15	
Steam	pounds	5357	7.50 [4]
Electricity	kWh	67	0.70 [4]
			<u>16.91</u>
RECYCLED PRINTING/WRITING PAPER PRODUCTION - TOTAL ENERGY USE			
Steam	pounds	6451	9.03
Electricity	kWh	682	7.16
Transportation - Diesel [5]	gallons	5	<u>0.72</u>
Total MMBtu/ton Recycled Printing and Writing Paper			16.91

Notes:

- [1] M. Sittig. "Pulp and Paper Manufacture". 1977.
- [2] Based on 7.5% of wastepaper removed as contaminants, in pulping and cleaning.
- [3] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.
- [4] Arthur D. Little. "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume V. Pulp and Paper Industry Report". 1976.
- [5] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).
- [6] Transportation of waste paper by truck - average travel distance 250 miles.

Figure III-A.9

VIRGIN UNBLEACHED COATED FOLDING BOXBOARD PRODUCTION

TABLE III-A.14

MATERIAL AND ENERGY INPUTS: VIRGIN UNBLEACHED COATED FOLDING BOXBOARD FORMING AND DRYING

PROCESS			MMBtu
Material Input		Units/ton	Equivalents/
Process Energy	Units	boxboard	ton boxboard
FURNISH REFINING, ADDITIVES MIXING, FINAL CLEANING, AND TEMP. ADJUSTMENT			
Unbleached Kraft Pulp	pounds	1720	
Rosin	pounds	30	
Alum	pounds	50	
Starch	pounds	18	
Steam	pounds	429	0.60 [1]
Electricity	kWh	64	0.67 [1]
FORMING, DRYING, CALENDERING, COATING AND WINDING (FOURDRINIER MACHINE)			
Stock (bone dry)	pounds	1818	
Coating	pounds	124	
Steam	pounds	9000	12.60 [2]
Electricity	kWh	1064	1.49 [2]
			15.36

BOXBOARD PRODUCTION - TOTAL ENERGY USE			
Steam	pounds	9000	13.20
Electricity	kWh	142	2.16
Total MMBtu/ton Boxboard			15.36

Notes:

[1] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.

[2] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).

TABLE III-A.15

**TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN UNBLEACHED COATED FOLDING
BOXBOARD PRODUCTION**

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	boxboard	Equivalents/ ton boxboard
KRAFT PULPING			
Pulp (bone dry)	pounds	1783	
Fuels:			
Gasoline	gallons	2	0.23
Diesel	gallons	1	0.19
Oil	gallons	9	1.34
Steam	pounds	6017	8.42
Electricity	kWh	69	0.73
Transportation-Diesel [1]	gallons	7	0.91
FOLDING BOXBOARD PRODUCTION			
Boxboard	pounds	2000	
Steam	pounds	9000	12.60
Electricity	kWh	142	1.49
			<u>25.91</u>

VIRGIN BOXBOARD PRODUCTION - TOTAL ENERGY USE

Fuels:			
Gasoline	gallons	2	0.23
Diesel	gallons	1	0.19
Oil	gallons	9	1.34
Steam	pounds	15017	21.02
Electricity	kWh	211	2.22
Transportation-Diesel [1]	gallons	7	0.91

Total MMBtu/Ton Virgin Boxboard   25.91

Breakdown of Process Energy Sources - Residue and Purchased:

Residue: Energy credits for by-product combustion from Kraft pulping	17.38
Purchased	8.53

Notes:

[1] Transportation of roundwood, forest and manufacturing residues to mill by truck - average travel distance estimated at 100 miles.

Figure III-A.10

RECYCLED UNBLEACHED COATED FOLDING BOXBOARD PRODUCTION

TABLE III-A.16

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED COATED FOLDING BOXBOARD PRODUCTION

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	boxboard [1]	Equivalents/ ton boxboard
WASTEPAPER PULPING			
Mixed waste paper	pounds	2054 [2]	
Electricity	kWh	397	4.17 [5]
Transportation - Diesel [6]	gallons	5	0.65 [6]
FURNISH REFINING, ADDITIVES MIXING, FINAL CLEANING, AND TEMP. ADJUSTMENT			
Pulp (bone dry)	pounds	1720 [1]	
Rosin	pounds	30	
Alum	pounds	50	
Starch	pounds	18	
Steam	pounds	429	0.60 [3]
Electricity	kWh	55	0.58 [3]
FORMING, PRESSING, DRYING, CALENDERING, WINDING, AND COATING			
Stock (bone dry)	pounds	1937 [1]	
Coating	pounds	124	
Steam	pounds	10429	14.60 [4]
Electricity	kWh	206	2.16 [4]
			22.75

RECYCLED BOXBOARD PRODUCTION - TOTAL ENERGY USE			
Steam	pounds	10857	15.20
Electricity	kWh	657	6.90
Transportation - Diesel [5]	gallons	5	0.65
Total MMBtu/ton Recycled Boxboard			22.75

Notes:

[1] M. Sittig. "Pulp and Paper Manufacture". 1977.

[2] Based on 7.5% of wastepaper removed as contaminants, in pulping and cleaning.

[3] Oak Ridge National Laboratory. "Energy Use and Distribution in the Pulp, Paper Boardmaking Industries", 1977.

[4] Arthur D. Little. "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Volume V. Pulp and Paper Industry Report". 1976.

[5] Energetics, Inc. "The U.S. Pulp and Paper Industry: An Energy Perspective", 1988 (based upon various sources from 1980-1985).

[6] Transportation of waste paper by truck - average travel distance 250 miles.

Figure III-A.11

PETROLEUM EXTRACTION AND REFINING

TABLE III-A.17

MATERIAL AND ENERGY INPUTS: ONSHORE NATURAL GAS EXTRACTION

PROCESS	MMBtu used/ MMBtu natural gas produced [1]	Units	Units/ton natural gas	MMBtu/ cubic foot natural gas [2]
Material Input				
Process Energy				
DEVELOPMENT DRILLING				
Fuels:				
Diesel	0.07	gallons	0.0005	7.42E-05
Total MMBtu/cf Natural Gas				7.42E-05

Notes:

[1] Original data in units of MMBtu used/MMBtu natural gas produced.

[2] 0.001031 MMBtu/cubic foot natural gas.

Numbers may not add up due to rounding.

Sources:

U.S. Department of Energy, "Energy Technology Characterizations Handbook," 1983, 120.

TABLE III-A.18

MATERIAL AND ENERGY INPUTS: ETHANE PRODUCTION

PROCESS			MMBtu used/ MMBtu natural	MMBtu/ cubic foot	Units/ton	MMBtu/ ton ethane
Material Input			gas produced [1]	natural gas [2]	ethane [3]	
Process Energy	Units					
NATURAL GAS PROCESSING [4]						
Sweet Gas	cubic feet				21255	
Fuels:						
Natural Gas	cubic feet	0.31	3.20E-04		6589	6.79
Sour Gas	cubic feet				21255	
Fuels:						
Natural Gas	cubic feet	1.13	1.17E-03		24061	24.81
Total MMBtu/ton Ethane						31.60

Notes:

[1] Original process energy data in units of MMBtu used/MMBtu natural gas produced.

[2] 0.001031 MMBtu/cubic foot natural gas.

[3] Cubic feet natural gas per ton ethane calculated from hhv of ethane equaling 21,914 Btu/pound.

[4] Assume 50% sweet gas and 50% sour gas.

Numbers may not add up due to rounding.

TABLE III-A.19

MATERIAL AND ENERGY INPUTS: PROPANE PRODUCTION

PROCESS			MMBtu used/ MMBtu natural	MMBtu/ cubic foot	Units/ton	MMBtu/ ton propane
Material Input			gas produced [1]	natural gas [2]	propane [3]	
Process Energy	Units					
NATURAL GAS PROCESSING [4]						
Sweet Gas	cubic feet				20886	
Fuels:						
Natural Gas	cubic feet	0.31	3.20E-04		6475	6.68
Sour Gas	cubic feet				20886	
Fuels:						
Natural Gas	cubic feet	1.13	1.17E-03		23642	24.38
Total MMBtu/ton Propane						31.05

Notes:

[1] Original process energy data in units of MMBtu used/MMBtu natural gas produced.

[2] 0.001031 MMBtu/cubic foot natural gas.

[3] Cubic feet natural gas per ton propane calculated from hhv of propane equaling 21,533 Btu/pound.

[4] Assume 50% sweet gas and 50% sour gas.

Numbers may not add up due to rounding.

Source for Tables III-A.18 & III-A.19:

U.S. Department of Energy, "Energy Technology Characterizations Handbook," 1983, 120.

TABLE III-A.20

MATERIAL AND ENERGY INPUTS: ONSHORE OIL EXTRACTION & DESALTING

PROCESS			MMBtus/MM	MMBtu
Material Input		Units/ton	Btus crude oil	Equivalents/
Process Energy	Units	crude oil	produced [1]	ton crude oil [2]
DEVELOPMENTAL DRILLING				
Fuels:				
Diesel	gallons	2	7.60E-03	0.29
CRUDE OIL EXTRACTION				
Fuels:				
Diesel	gallons	2	7.16E-03	0.27
CRUDE OIL DESALTING				
Crude Oil	pounds	2000		
Fuels:				
Other [3]				0.0002
Electricity - Purchased	kWh	0.62		0.007
				0.57

PRIMARY ONSHORE OIL EXTRACTION & DESALTING - TOTAL ENERGY USE				
Crude Oil	pounds	2000		
Fuels:				
Diesel	gallons	4		0.56
Other [3]				0.0002
Electricity	kWh	2.57		0.01
				0.57
			Total MMBtu/ton Crude Oil	0.57

Notes:

[1] Data originally in MMBtu used/MMBtu crude oil produced.

[2] Using conversion factor of 138,100 Btu/gallon crude oil.

[3] Process fuel not specified.

Numbers may not add up due to rounding.

Sources:

U.S. Department of Energy, "Energy Technology Characterizations Handbook," 1983, 106-107.

Gaines & Wolsky, "Energy and Materials Flows in Petroleum Refining," U.S. Department of Energy, 1981, pp. 63-65.

TABLE III-A.21
MATERIAL AND ENERGY INPUTS: CRUDE OIL PROCESSING

PROCESS

Material Input			
Process Energy		Units/ton	MMBtu
Coproducts	Units	feed	Equivalents/ton feed
ATMOSPHERIC DISTILLATION			
Crude Oil	pounds	2900	
Fuels:			
Other [1]			0.57
Electricity - Purchased	kWh	4	0.04
Steam [2]	pounds	103	0.14
C4 and Lighter	pounds	52	-0.02
Naphtha	pounds	433	-0.16
Gas Oil	pounds	636	-0.24
Atmospheric Bottoms	pounds	879	-0.33
VACUUM DISTILLATION			
Fuels:			
Other [1]			0.41
Electricity - Purchased	kWh	2	0.02
Steam [2]	pounds	135	0.19
CATALYTIC CRACKING			
Fuels:			
Other [1]			0.65
Electricity - Purchased	kWh	22	0.23
Steam [2]	pounds	305	0.43

Notes:

[1] Process fuel not specified.

[2] In original source, steam converted to pounds using conversion of 1100 Btu/pound; converted to pounds here using 1400 Btu/pound (from identical MMBtu value).

Sources:

Gaines & Wolsky, "Energy and Materials Flows in Petroleum Refining," U.S. Department of Energy, 1981, 63-65.

TABLE III-A.21.a

MATERIAL AND ENERGY INPUTS: NAPHTHA FROM ATMOSPHERIC DISTILLATION

PROCESS

Material Output			MMBtu
Process Energy		Units/ton	Equivalents/ton
<i>Coproducts</i>	Units	naphtha	naphtha
ATMOSPHERIC DISTILLATION			
Desalted Crude Oil	pounds	9240	
Fuels:			
Other			2.63
Electricity - Purchased		19	0.20
Steam	pounds	476	0.67
<i>C4 and Lighter</i>	pounds	240	-0.09
<i>Gas Oil</i>	pounds	2940	-1.11
<i>Atmospheric Bottoms</i>	pounds	4060	-1.54
Total MMBtu/ton Naphtha			0.76

Notes:

Numbers may not add up due to rounding.

Sources:

Gaines & Wolsky, "Energy and Materials Flows in Petroleum Refining," U.S. Department of Energy, 1981, 63-65.

Previous Tables.

TABLE III-A.21.b

MATERIAL AND ENERGY INPUTS: NAPHTHA FROM CATALYTIC CRACKING

PROCESS	Material Input	Units	Units/ton naphtha	MMBtu Equivalents/ ton naphtha
	Process Energy			
VACUUM DISTILLATION				
	Atmospheric Bottoms [1]	pounds	2180	
	Fuels:			
	Other			0.44
	Electricity - Purchased	kWh	5	0.02
	Steam	pounds	336	0.21
CATALYTIC CRACKING (FCC)				
	Fuels:			
	Other			0.71
	Electricity - Purchased	kWh	54	0.25
	Steam	pounds	758	0.47
				2.10

TOTAL ENERGY USE - NAPHTHA FROM CATALYTIC CRACKING				
	Atmospheric Bottoms	pounds	2180	
	Fuels:			
	Other			1.15
	Electricity - Purchased	kWh	60	0.27
	Steam	pounds	1093	0.67
	Total MMBtu/ton Naphtha			2.10

Notes:

[1] 1.09 tons atmospheric bottoms/ton naphtha.

Numbers may not add up due to rounding.

Source:

Gaines & Wolsky, "Energy and Materials Flows in Petroleum Refining," U.S. Department of Energy, 1981, 63-65.

Previous Tables.

TABLE III-A.21.c

MATERIAL AND ENERGY INPUTS: GAS OIL FROM ATMOSPHERIC DISTILLATION

PROCESS

Material Output			MMBtu
Process Energy		Units/ton	Equivalents/ton
<i>Coproducts</i>	<i>Units</i>	<i>gas oil</i>	<i>gas oil</i>
ATMOSPHERIC DISTILLATION			
Desalted Crude Oil	pounds	6286	
Fuels:			
Other			1.79
Electricity - Purchased		13	0.14
Steam	pounds	324	0.45
<i>C4 and Lighter</i>	pounds	163	-0.06
<i>Naphtha</i>	pounds	1361	-0.51
<i>Atmospheric Bottoms</i>	pounds	2762	-1.04
Total MMBtu/ton Gas Oil			0.76

Notes:

Numbers may not add up due to rounding.

Sources:

Gaines & Wolsky, "Energy and Materials Flows in Petroleum Refining," U.S. Department of Energy, 1981, 63-65.

Previous Tables.

Figure III-A.12

ETHYLENE PRODUCTION

TABLE III-A.22

MATERIAL AND ENERGY INPUTS: ETHYLENE PRODUCTION FROM MIX OF FEEDS [1]

PROCESS

Material Input			MMBtu
Process Energy		Units/ton	Equivalents/ton
<i>Coproducts</i>	<i>Units</i>	<i>ethylene</i>	<i>ethylene</i>
ETHYLENE FROM MIX OF FEEDS [2]			
Ethane	pounds	847	
Propane	pounds	631	
Naphtha	pounds	1749	
Heavy Gas Oil	pounds	2181	
Purchased Fuel [3]			4.68
Fuel burned from byproducts			23.50
Propylene	pounds	726	-3.78
C4 [4]	pounds	432	-2.25
Pyrolysis Gasoline	pounds	822	-4.28
C5+	pounds	61	-0.32
Fuel Oil	pounds	551	-2.87
Total MMBtu/ton Ethylene			14.68

Breakdown of Energy Sources - Byproducts and Purchased: [5]

Energy from byproduct combustion:	23.50
Purchased:	4.68

Notes:

[1] Energy data calculated from Tables III-A.22a-d.

[2] Mix of Feeds: 33.6% ethane; 13.1% propane; 26.9% naphtha; 26.4% heavy gas oil.

[3] Purchased fuel not specified.

[4] C4 = butadiene, butylene, and butane.

[5] 816 pounds of off gases, used as fuel in the pyrolysis furnace or in an on-site utility, is also produced. Numbers may not add up due to rounding.

Sources:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1982, 74-84.

Henri Ulrich, "Raw Materials for Industrial Polymers," Oxford University Press: New York, NY, 1988, pp. 59. Previous Tables.

TABLE III-A.22.a

MATERIAL AND ENERGY INPUTS: ETHYLENE PRODUCTION FROM ETHANE

PROCESS

Material Input			
Process Energy	Pounds/ton	Btu/lb	MMBtu/ton
<i>Coproducts</i>	<i>ethylene</i>	<i>ethylene</i>	<i>ethylene</i>
ETHYLENE FROM ETHANE			
Ethane	1.26		
Fuel burned from byproducts		4,050	8.10
Purchased Fuel [1]		5,910	11.82
Propylene	0.03	-198	-0.40
C4 [2]	0.03	-261	-0.52
Pyrolysis Gasoline	0.01	-79	-0.16
C5+	0.03	-221	-0.44
			18.40
Breakdown of Energy Sources - Byproducts and Purchased: [3]			
Energy from byproduct combustion:			8.10
Purchased:			11.82

Notes:

[1] Purchased fuel not specified.

[2] C4 = butadiene, butylene, and butane.

[3] 0.16 pounds of off gases, used as fuel in the pyrolysis furnace or in an on-site utility, is also produced.

Totals may not add up due to rounding.

Source:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1980, pp. 74-84.

TABLE III-A.22.b

MATERIAL AND ENERGY INPUTS: ETHYLENE PRODUCTION FROM PROPANE

PROCESS

Material Input				
Process Energy	Pounds/ton	Btu/lb	MMBtu/ton	
<i>Coproducts</i>	<i>ethylene</i>	<i>ethylene</i>	<i>ethylene</i>	
ETHYLENE FROM PROPANE				
Propane	2.41			
Fuel burned from byproducts		4,694	9.39	
Purchased Fuel [1]		2,705	5.41	
Propylene	0.41	-1,259	-2.52	
C4 [2]	0.08	-246	-0.49	
Pyrolysis Gasoline	0.08	-246	-0.49	
C5+	0.16	-491	-0.98	
				10.32

Breakdown of Energy Sources - Byproducts and Purchased: [3]

Energy from byproduct combustion:	9.39
Purchased:	5.41

Notes:

[1] Purchased fuel not specified.

[2] C4 = butadiene, butylene, and butane.

[3] 0.68 pounds of off gases, used as fuel in the pyrolysis furnace or in an on-site utility, is also produced.

Totals may not add up due to rounding.

Source:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1980, pp. 74-84.

TABLE III-A.22.c

MATERIAL AND ENERGY INPUTS: ETHYLENE PRODUCTION FROM NAPHTHA

PROCESS

Material Input			
Process Energy	Pounds/ton	Btu/lb	MMBtu/ton
<i>Coproducts</i>	<i>ethylene</i>	<i>ethylene</i>	<i>ethylene</i>
ETHYLENE FROM NAPHTHA			
Naphtha from Atm. Dist.	1.63		
Naphtha from Cat. Cracking	1.63		
Fuel burned from byproducts		17,600	35.20
Purchased Fuel			
<i>Propylene</i>	0.53	-2,870	-5.74
<i>C4 [1]</i>	0.31	-1,679	-3.36
<i>Pyrolysis Gasoline</i>	0.73	-3,953	-7.91
<i>Fuel Oil</i>	0.14	-758	-1.52
			16.68
Breakdown of Energy Sources - Byproducts and Purchased: [2]			
Energy from byproduct combustion:			35.20
Purchased:			0

Notes:

[1] C4 = butadiene, butylene, and butane.

[2] 0.54 pounds of off gases, used as fuel in the pyrolysis furnace or in an on-site utility, is also produced.

Totals may not add up due to rounding.

Source:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1980, pp. 74-84.

TABLE III-A-22.d

MATERIAL AND ENERGY INPUTS: ETHYLENE PRODUCTION FROM HEAVY GAS OIL

PROCESS

Material Input			
Process Energy	Pounds/ton	Btu/lb	MMBtu/ton
<i>Coproducts</i>	<i>ethylene</i>	<i>ethylene</i>	<i>ethylene</i>
ETHYLENE FROM HEAVY GAS OIL			
Heavy Gas Oil	4.13		
Fuel burned from byproducts		19,085	38.17
Purchased Fuel			
<i>Propylene</i>	0.60	-2,773	-5.55
<i>C4 [1]</i>	0.42	-1,941	-3.88
<i>Pyrolysis Gasoline</i>	0.76	-3,512	-7.02
<i>Fuel Oil</i>	0.90	-4,159	-8.32
			<u>13.40</u>

Breakdown of Energy Sources - Byproducts and Purchased: [2]

Energy from byproduct combustion:	38.17
Purchased:	0

Notes:

[1] C4 = butadiene, butylene, and butane.

[2] 0.45 pounds of off gases, used as fuel in the pyrolysis furnace or in an on-site utility, is also produced.

Totals may not add up due to rounding.

Source:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1980, pp. 74-84.

TABLE III-A.23

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN ETHYLENE PRODUCTION

PROCESS	Material Output	Units	Units/ton ethylene	MMBtu Equivalents/ton ethylene
	Process Energy			
	Coproducts			
NATURAL GAS DRILLING				
	Natural Gas	cubic feet	31185	
	Fuels:			
	Diesel	gallons	17	2.31
	Transportation - Natural Gas [1]	cubic feet	756	0.78
NATURAL GAS PROCESSING-ETHANE EXTRACTION				
	Ethane	pounds	847	
	Fuels:			
	Natural Gas	cubic feet	12980	13.38
NATURAL GAS PROCESSING-PROPANE EXTRACTION				
	Propane	pounds	631	
	Fuels:			
	Natural Gas	cubic feet	9502	9.80
CRUDE OIL EXTRACTION AND DESALTING				
	Crude Oil	pounds	6851	
	Fuels:			
	Diesel	gallons		1.91
	Other			0.001
	Electricity - Purchased	kWh	9	0.02
	Transportation - Diesel [2]	gallons	25	3.42
	Transportation - Natural Gas [2]	cubic feet	2326	2.40
ATMOSPHERIC DISTILLATION				
	Naphtha	pounds	875	
	Gas Oil	pounds	2180	
	Atmospheric Bottoms	pounds	953	
	Fuels:			
	Other			1.95
	Electricity - Purchased	kWh	14	0.15
	Steam	pounds	353	0.49
	C4 & Lighter	pounds	178	-0.27
	Naphtha	pounds	608	-0.92
	Gas Oil	pounds	0	0.00
	Atmospheric Bottoms	pounds	2057	-3.11
NAPHTHA FROM CATALYTIC CRACKING				
	Naphtha	pounds	875	
	Fuels:			
	Other			0.55
	Electricity - Purchased	kWh	11	0.12
	Steam	pounds	210	0.29

TABLE III-A.23 (CONTINUED)
TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN ETHYLENE PRODUCTION

PROCESS

Material Output			
Material Input			
Process Energy		Units/ton	MMBtu
Coproducts	Units	ethylene	Equivalents/ton
			ethylene
ETHYLENE PRODUCTION FROM MIX OF FEEDS [3]			
Ethylene	pounds	2000	
Fuels:			
Purchased Fuel			4.68
Fuel burned from byproducts			23.50
Propylene	pounds	726	-3.78
C4	pounds	432	-2.25
Pyrolysis Gasoline	pounds	822	-4.28
C5+	pounds	61	-0.32
Fuel Oil	pounds	551	-2.87
			47.96

TOTAL ENERGY USE - ETHYLENE PRODUCTION

Fuels:			
Diesel	gallons	30	4.23
Natural Gas	cubic feet	22482	23.18
Other [4]			30.68
Electricity - Purchased	kWh	34	0.29
Steam	pounds	563	0.79
Transportation - Diesel	gallons	25	3.42
Transportation - Natural Gas	cubic feet	3081	3.18
Coproducts			-17.79

Total MMBtu/ton Virgin Ethylene Production 47.96

Notes:

- [1] Transportation energy calculated from MMBtu/ton of natural gas in virgin transportation analysis using conversion factor of 19.0 cubic feet/pound natural gas.
- [2] Transportation energy disaggregated between diesel (ship) and natural gas (pipeline).
- [3] Mix of Feeds: 33.6% ethane; 13.1% propane; 26.9% naphtha; 26.4% heavy gas oil.
- [4] Includes "purchased fuel," "fuel burned from byproducts," and "other."

Sources:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1982, 74-84.
Henri Ulrich, "Raw Materials for Industrial Polymers," Oxford University Press: New York, NY, 1988, pp. 59.
Previous Tables.

Figure III-A.13

VIRGIN HDPE PELLET PRODUCTION

TABLE III-A.24

MATERIAL AND ENERGY INPUTS: VIRGIN HDPE POLYMERIZATION

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	HDPE	Equivalents/ton
			HDPE
LOW PRESSURE GAS PHASE POLYMERIZATION [1]			
Ethylene	pounds	2040	
Electricity - Purchased	kWh	273	2.87
Total MMBtu/ton HDPE Pellets			2.87

Notes:

[1] Production of HDPE using the low-pressure, gas phase UNIPOL process; resin is discharged in granular (pellet) form.

Numbers may not add up due to rounding.

Sources:

Hydrocarbon Processing, "Petrochemical Handbook," November, 1989.

TABLE III-A.25

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN HDPE PELLET PRODUCTION

PROCESS

Material Output			MMBtu
Process Energy		Units/ton	Equivalents/ton
<i>Coproducts</i>	Units	HDPE	HDPE
ETHYLENE PRODUCTION [1]			
Ethylene	pounds	2040	
Fuels:			
Diesel	gallons	31	4.31
Natural Gas	cubic feet	22932	23.64
Other			31.29
Electricity - Purchased	kWh	28	0.30
Steam	pounds	574	0.80
Transportation - Diesel	gallons	25	3.49
Transportation - Natural Gas	cubic feet	3143	3.24
<i>Coproducts</i>			-18.15
HDPE POLYMERIZATION			
HDPE Pellets	pounds	2000	
Electricity - Purchased	kWh	273	2.87
			51.79

TOTAL ENERGY USE - HDPE PELLET PRODUCTION

Fuels:			
Diesel	gallons	31	4.31
Natural Gas	cubic feet	22932	23.64
Other			31.29
Electricity - Purchased	kWh	301	3.16
Steam	pounds	574	0.80
Transportation - Diesel	gallons	25	3.49
Transportation - Natural Gas	cubic feet	3143	3.24
<i>Coproducts</i>			-18.15

Total MMBtu/ton Virgin HDPE Pellets 51.79

Notes:

[1] Refer to Table III-A.23.

Numbers may not add up due to rounding.

Sources:

Previous Tables.

Figure III-A.14

RECYCLED HDPE PELLET PRODUCTION

Baled HDPE
Containers

TABLE III-A.26

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED HDPE PELLET PRODUCTION

PROCESS			MMBtu
Material Input		Units/ton	Equivalents/ton
Process/Transportation Energy	Units	HDPE	HDPE
PLASTICS PROCESSING			
HDPE Containers	pounds	2000	
Electricity - Purchased [1]	kWh	1000	10.50
Transportation - Diesel	gallons	5	0.63
Total MMBtu/ton Recycled HDPE Pellets			11.13

Notes:

[1] Average of range of 500-1500 kWh/ton plastics produced for all steps from baled plastics to pellets, including hot water heating.

Source:

Personal communication with Bruce Bond, WTE Corporation, January 1992.

Figure III-A.15

VIRGIN LDPE PELLET PRODUCTION

TABLE III-A.27

MATERIAL AND ENERGY INPUTS: VIRGIN LDPE POLYMERIZATION

PROCESS		Units/ton		MMBtu
Material Input				Equivalents/ton
Process Energy	Units	LDPE		LDPE [1]
HIGH PRESSURE POLYMERIZATION [2]				
Ethylene	pounds	2100		
Electricity - Purchased	kWh	1257		13.20
Steam	pounds	1500		2.10
Total MMBtu/ton LDPE Pellets				15.30

Notes:

[1] Process energy originally reported in Btu.

[2] Includes extrusion, pelletizing and drying.

Numbers may not add up due to rounding.

Source:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1982, 119.

TABLE III-A.28

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN LDPE PELLET PRODUCTION

PROCESS

Material Output			MMBtu
Process Energy		Units/ton	Equivalents/ton
<i>Coproducts</i>	Units	LDPE	LDPE
ETHYLENE PRODUCTION [1]			
Ethylene	pounds	2100	
Fuels:			
Diesel	gallons	32	4.44
Natural Gas	cubic feet	23606	24.34
Other			32.21
Electricity - Purchased	kWh	29	0.30
Steam	pounds	591	0.83
Transportation - Diesel	gallons	26	3.59
Transportation - Natural Gas	cubic feet	3235	3.34
<i>Coproducts</i>			-18.68
LDPE POLYMERIZATION			
LDPE Pellets	pounds	2000	
Electricity - Purchased	kWh	1257	13.20
Steam	pounds	1500	2.1
			65.66

TOTAL ENERGY USE - LDPE PELLET PRODUCTION

Fuels:			
Diesel	gallons	32	4.44
Natural Gas	cubic feet	23606	24.34
Other			32.21
Electricity - Purchased	kWh	1286	13.50
Steam	pounds	2091	2.93
Transportation - Diesel	gallons	26	3.59
Transportation - Natural Gas	cubic feet	3235	3.34
<i>Coproducts</i>			-18.68

Total MMBtu/ton Virgin LDPE Pellets 65.66

Notes:

[1] Refer to Table III-A.23.

Numbers may not add up due to rounding.

Sources:

Previous Tables.

Figure III-A.16

RECYCLED LDPE PELLET PRODUCTION

TABLE III-A.29

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED LDPE PELLET PRODUCTION

PROCESS		MMBtu	
Material Input		Units/ton	Equivalents/ton
Process/Transportation Energy	Units	LDPE	LDPE
PLASTICS PROCESSING			
LDPE Films & Bags	pounds	2000	
Electricity - Purchased [1]	kWh	1500	15.75
Transportation - Diesel	gallons	9	1.25
Total MMBtu/ton Recycled LDPE Pellets			17.00

Notes:

[1] High end of range of 500-1500 kWh/ton plastics produced for all steps from baled plastics to pellets, including hot water heating (higher number reflects higher level of cleaning and processing necessary for LDPE recycling).

Source:

Personal communication with Bruce Bond, WTE Corporation, January 1992.

Figure III-A.17

PARAXYLENE PRODUCTION

TABLE III-A.30

MATERIAL AND ENERGY INPUTS: PARAXYLENE PRODUCTION

PROCESS			
Material Input			MMBtu
Process Energy		Units/ton	Equivalents/ton
<i>Coproducts</i>	Units	<i>paraxylene</i> [1]	<i>paraxylene</i>
HYDROTREATING			
Naphtha [2]	pounds	4750	
Fuels:			
Other [3]			0.49
Electricity - Purchased	kWh	14	0.15
Steam	pounds	110	0.15
CATALYTIC REFORMING			
Naphtha			
Fuels:			
Other [3]			1.71
Electricity - Purchased	kWh	25	0.26
Steam	pounds	53	0.07
XYLENE from REFORMATE			
Reformate			
Electricity - Purchased	kWh	20	0.21
Steam	pounds	3184	4.46
Raffinate	pounds	2250	-3.56
PARAXYLENE from MIXED XYLENES [4]			
Mixed Xylenes			
Electricity - Purchased	kWh	114	1.20
Steam	pounds	10714	15.00
Light Ends	pounds	500	-2.12
			18.04

TOTAL ENERGY USE - PARAXYLENE PRODUCTION			
Naphtha [2]	pounds	4750	
Fuels:			
Other [3]			2.21
Electricity - Purchased	kWh	174	1.83
Steam	pounds	14061	19.69
<i>Coproducts</i>			-5.68
			18.04
Total MMBtu/ton Paraxylene			18.04

Notes:

[1] Process energy originally reported in MMBtu.

[2] Naphtha: 50% from atmospheric distillation.

[3] Process fuel not specified.

[4] Process energy numbers, Council for Solid Waste Solutions, Steve Teslik, January 21, 1992.

Numbers may not add up due to rounding.

Source:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1980, pp. 74-84.

Figure III-A.18

VIRGIN PET PELLET PRODUCTION FROM DMT

TABLE III-A.31

MATERIAL AND ENERGY INPUTS: ETHYLENE GLYCOL FROM ETHYLENE

PROCESS		MMBtu	
Material Input		Units/ton	Equivalents/
Process Energy	Units	ethylene glycol	ton ethylene glycol
OXIDATION			
Ethylene	pounds	1460	
Oxygen	pounds	1580	
Fuels:			
Other			3.80
Electricity - Purchased	kWh	221	2.32
Total MMBtu/ton Ethylene Glycol			6.12

Source:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1980, p. 156.

TABLE III-A.32

MATERIAL AND ENERGY INPUTS: PET PELLET PRODUCTION FROM DMT

PROCESS

Material Input			MMBtu
Process Energy		Units/ton	Equivalents/
Coproducts	Units	PET	ton PET
OXIDATION OF PARAXYLENE (DMT PRODUCTION)			
Paraxylene	pounds	1180	
Methanol [1]	pounds	760	
Fuels:			
Other [2]			6.48
Electricity - Purchased	kWh	190	2.00
CONDENSATION POLYMERIZATION			
Ethylene Glycol	pounds	700	
Dimethyl Terephthalate (from above reaction)			
Fuels:			
Other [2]			4.54
Electricity - Purchased	kWh	54	0.60
Methanol	pounds	660	n/a
			13.62

TOTAL ENERGY USE - PET FROM DIMETHYL TEREPHTHALATE			
Paraxylene	pounds	1180	
Methanol [1]	pounds	760	
Ethylene Glycol	pounds	700	
Dimethyl Terephthalate			
Fuels:			
Other [2]			11.02
Electricity - Purchased	kWh	248	2.60
Coproducts	pounds	660	n/a
Total MMBtu/ton PET Pellets			13.62

Notes:

[1] Process energy for methanol production unavailable.

[2] Other is fuel/steam (disaggregated data unavailable).

Numbers may not add due to rounding.

Source:

Gaines and Shen, "Energy and Materials Flows in the Production of Olefins and their Derivatives," 1980, page 143.

Personal communication, Steve Teslik, Council for Solid Waste Solutions, January 21, 1992 (paraxylene and ethylene glycol usage factors, and electricity requirements).

TABLE III-A.33

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN PET PELLET PRODUCTION

PROCESS

Material Output			MMBtu
Process Energy		Units/ton	Equivalents/ton
<i>Coproducts</i>	Units	PET	PET
ETHYLENE PRODUCTION [1]			
Ethylene	pounds	511	
Fuels:			
Diesel	gallons	8	1.08
Natural Gas	cubic feet	5744	5.92
Other			7.84
Electricity - Purchased	kWh	7	0.07
Steam	pounds	144	0.20
Transportation - Diesel	gallons	6	0.87
Transportation - Natural Gas	cubic feet	787	0.81
<i>Coproducts</i>			-4.55
ETHYLENE GLYCOL PRODUCTION			
Ethylene Glycol	pounds	700	
Fuels:			
Other			1.33
Electricity - Purchased	kWh	77	0.81
CRUDE OIL EXTRACTION AND DESALTING			
Crude Oil	pounds	6474	
Fuels:			
Diesel	gallons		1.81
Other			0.001
Electricity - Purchased	kWh	2	0.02
Transportation - Diesel [2]	gallons	23	3.23
Transportation - Natural Gas [2]	cubic feet	2198	2.27
NAPHTHA from ATMOSPHERIC DISTILLATION			
Naphtha	pounds	1401	
Atmospheric Bottoms	pounds	1527	
Fuels:			
Other			1.84
Electricity - Purchased	kWh	13	0.14
Steam	pounds	333	0.47
C4 & Lighter	pounds	168	-0.25
Naphtha	pounds	0	0.00
Gas Oil	pounds	2060	-3.11
Atmospheric Bottoms	pounds	1317	-1.99
NAPHTHA from CATALYTIC CRACKING			
Naphtha	pounds	1401	
Fuels:			
Other			0.81
Electricity - Purchased	kWh	18	0.19
Steam	pounds	337	0.47

TABLE III-A.33 (CONTINUED)

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN PET PELLET PRODUCTION

PROCESS

Material Output			MMBtu
Process Energy		Units/ton	Equivalents/ton
<i>Coproducts</i>	Units	PET	PET
PARAXYLENE PRODUCTION			
Paraxylene	pounds	1180	
Fuels:			
Other			1.30
Electricity - Purchased	kWh	103	1.08
Steam	pounds	8296	11.61
<i>Coproducts</i>			-3.35
PET PRODUCTION from DMT			
PET	pounds	2000	
Fuels:			
Other			11.02
Electricity - Purchased	kWh	248	2.60
Methanol Recovery	pounds	640	n/a
			44.55

TOTAL ENERGY USE - VIRGIN PET FIBER PRODUCTION

Fuels:			
Diesel	gallons		2.89
Natural Gas	cubic feet		5.92
Other			24.14
Electricity - Purchased	kWh	468	4.92
Steam	pounds	9110	12.75
Transportation - Diesel	gallons	30	4.11
Transportation - Natural Gas	cubic feet	2985	3.08
<i>Coproducts</i>			-13.25
Total MMBtu/ton Virgin Polyethylene Terephthalate			44.55

Notes:

[1] Refer to Table III-A.23.

[2] Transportation energy disaggregated between diesel (ship) and natural gas (pipeline).

Numbers may not add up due to rounding.

Sources:

Previous tables.

Figure III-A.19
RECYCLED PET PELLET PRODUCTION

Baled PET Containers

TABLE III-A.34

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED PET PELLET PRODUCTION

PROCESS		MMBtu	
Material Input		Units/ton	Equivalents/ton
Process/Transportation Energy	Units	PET	PET
PLASTICS PROCESSING			
PET Containers	pounds	2000	
Electricity - Purchased [1]	kWh	1000	10.50
Transportation - Diesel	gallons	9	1.25
Total MMBtu/ton Recycled PET Pellet			11.75

Notes:

[1] Average of range of 500-1500 kWh/ton plastics produced for all steps from baled plastics to pellets, including hot water heating.

Source:

Personal communication with Bruce Bond, WTE Corporation, January 1992.

Figure III-A.20

VIRGIN MOLTEN GLASS PRODUCTION

TABLE III-A.35

MATERIAL AND ENERGY INPUTS: LIMESTONE MINING AND PROCESSING

PROCESS			MMBtu
Material Input		Units/ton	Equivalents/
Process Energy	Units	limestone	ton limestone
LIMESTONE MINING			
Fuels:			
Diesel	gallons	0.15	0.02
Other [1]			0.01
Electricity - Purchased	kWh	0.30	0.003
LIMESTONE CRUSHING			
Limestone	pounds		
Fuels:			
Natural Gas	cubic feet	12	0.01
Other [1]			0.01
Electricity - Purchased	kWh	3	0.04
			0.09

LIMESTONE MINING AND PROCESSING - TOTAL ENERGY USE			
Fuels:			
Diesel	gallons	0.15	0.02
Natural Gas	cubic feet	12	0.01
Other [1]			0.02
Electricity - Purchased	kWh	4	0.04
			0.09
	Total MMBtu/ton Limestone		0.09

Notes:

[1] Other fuels not specified.

Sources:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines, citing: "SIC 1422 Crushed and Broken Limestone," U.S. Department of Commerce, Bureau of the Census, 1970.

TABLE III-A.36

MATERIAL AND ENERGY INPUTS: FELDSPAR MINING AND PROCESSING

PROCESS	Material Input	Units	Units/ton feldspar	MMBtu Equivalents/ ton feldspar
	Process Energy			
FELDSPAR MINING				
	Fuels:			
	Diesel	gallons	0.37	0.05
	Electricity - Purchased	kWh	2	0.03
PRIMARY & SECONDARY CRUSHING				
	Electricity - Purchased	kWh	3	0.04
ROD MILLING				
	Electricity - Purchased	kWh	11	0.12
CLASSIFICATION				
	Electricity - Purchased	kWh	3	0.03
MICA FLOATATION				
	Fuels:			
	Diesel	gallons	0.37	0.05
	Electricity - Purchased	kWh	3	0.03
GARNET FLOATATION				
	Electricity - Purchased	kWh	2	0.02
FELDSPAR FLOATATION				
	Fuels:			
	Diesel	gallons	0.37	0.05
	Electricity - Purchased	kWh	3	0.03
DEWATERING				
	Electricity - Purchased	kWh	4	0.04
DRYING				
	Fuels:			
	Diesel	gallons	6	0.78
	Electricity - Purchased	kWh	4	0.04
BAGGING/LOADING				
	Electricity - Purchased	kWh	2	0.02
				1.33

FELDSPAR MINING AND PROCESSING - TOTAL ENERGY USE				
	Fuels:			
	Diesel	gallons	7	0.93
	Electricity - Purchased	kWh	38	0.40
				1.33
			Total MMBtu/ton Feldspar	1.33

Sources:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

TABLE III-A.37
MATERIAL AND ENERGY INPUTS: MOLTEN GLASS PRODUCTION
25% CULLET CONTENT

PROCESS		Units /ton molten glass	MMBtu Equivalents/ton molten glass
Material Output			
Process Energy	Units		
CULLET CRUSHING [1]			
Crushed Glass	pounds	500	
Electricity - Purchased	kWh	10	0.11
BATCH HANDLING AND RAW MATERIALS MIXING [2]			
Sand	pounds	1050	
Limestone	pounds	296	
Feldspar	pounds	90	
Soda ash	pounds	330	
Furnace Ready Cullet	pounds	500	
Electricity - Purchased	kWh	22	0.23
MELTING			
Fuels:			
Natural Gas	cubic feet	4607	4.75
Electricity - Purchased	kWh	19	0.20
			5.29

TOTAL ENERGY USE - MOLTEN GLASS PRODUCTION			
Fuels:			
Natural Gas	cubic feet	4607	4.75
Electricity - Purchased	kWh	51	0.54
			5.29
Total MMBtu/Ton Molten Glass			5.29

Notes:

[1] Post-consumer cullet coming from MRF not furnace ready; energy for cullet crushing is difference between .34 MMBtu reported by OB for batch handling/cullet crushing of not furnace ready cullet and .23 MMBtu for furnace ready cullet.

[2] Material requirements for raw materials provided by GPI and OB for 100% virgin batch mix. Requirements scaled to 75% because this "virgin" system is modelled using 25% cullet.

Sources:

Personal communication Glass Packaging Institute, February 21, 1991.

Personal communication with John LeBlanc, Owens-Brockway, October 4, 1991 and May 29, 1992.

TABLE III-A.38

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN GLASS PRODUCTION

25% CULLET CONTENT

PROCESS	Material Output	Units	Units /ton molten glass	MMBtu Equivalents/ton molten glass [1]
	Process/Transportation Energy			
SAND MINING & PROCESSING [2]				
	Sand	pounds	1050	
	Other [3]			0.25
	Transportation-Diesel [4]	gallons	0.60	0.08
LIMESTONE MINING & PROCESSING [2]				
	Limestone	pounds	296	
	Fuels:			
	Diesel	gallons	0.02	0.003
	Natural Gas	cubic feet	2	0.002
	Other			0.003
	Electricity - Purchased	kWh	1	0.01
	Transportation-Diesel [4]	gallons	0.07	0.01
FLEDSPAR MINING & PROCESSING [2]				
	Feldspar	pounds	90	
	Fuels:			
	Diesel	gallons	0.30	0.04
	Electricity - Purchased	kWh	2	0.02
	Transportation-Diesel [4]	gallons	0.03	0.005
SODA ASH MINING & PROCESSING [2]				
	Soda ash	pounds	330	
	Other [3]			1.11
	Transportation-Diesel [4]	gallons	0.43	0.06
CULLET CRUSHING				
	Furnace Ready Cullet	pounds	500	
	Electricity - Purchased	kWh	10	0.11
	Transportation-Diesel [5]	gallons	1.14	0.16
BATCH HANDLING				
	Electricity - Purchased	kWh	22	0.23
MELTING				
	Molten Glass			
	Fuels:			
	Natural Gas	cubic feet	4607	4.75
	Electricity - Purchased	kWh	19	0.20
				7.03

TABLE III-A.38 (CONTINUED)

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN GLASS PRODUCTION

25% CULLET CONTENT

PROCESS		Units /ton	MMBtu
Material Output		molten	Equivalents/ton
Process/Transportation Energy	Units	glass	molten glass [1]
VIRGIN MOLTEN GLASS PRODUCTION - TOTAL ENERGY USE			
Fuels:			
Diesel	gallons	0.32	0.05
Natural Gas	cubic feet	4609	4.75
Other [3]			1.36
Electricity - Purchased	kWh	54	0.56
Transportation-Diesel	gallons		0.31
Total MMBtu/Ton Virgin Molten Glass			7.03

Notes:

- [1] Process energy originally reported in MMBtu for all but limestone and feldspar production.
- [2] Material requirements (and energy requirements for sand and soda ash) for raw materials provided by GPI and OB for 100% virgin batch mix. Requirements scaled to 75% because this "virgin" system is modelled using 25% cullet
- [3] Disaggregated energy data unavailable; total energy input listed as "other".
- [4] Transportation energies based on MMBtu/ton calculated for glass raw materials.
- [5] Transportation energy based on MMBtu/ton cullet as calculated in recycled transportation energy impacts system.

Sources:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

Personal communication Glass Packaging Institute, February 21, 1991.

Personal communication with John LeBlanc, Owens-Brockway, October 4, 1991 and May 29, 1992.

Figure III-A.21

RECYCLED MOLTEN GLASS PRODUCTION

TABLE III-A.39

**TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED MOLTEN GLASS PRODUCTION -
100% CULLET CONTENT**

PROCESS		Units /ton	MMBtu
Material Input		molten	Equivalents/ton
Process/Transportation Energy	Units	glass	molten glass [1]
CULLET CRUSHING [2]			
Crushed Glass	pounds	2000	
Electricity - Purchased	kWh	30	0.32
Transportation-Diesel	gallons	5	0.63
BATCH HANDLING			
Electricity - Purchased	kWh	22	0.23
MELTING			
Fuels:			
Natural Gas	cubic feet	3637	3.75
Electricity - Purchased	kWh	19	0.20
			<u>5.12</u>

RECYCLED MOLTEN GLASS PRODUCTION - TOTAL ENERGY USE			
Fuels:			
Natural Gas	cubic feet	3637	3.75
Electricity - Purchased	kWh	71	0.75
Transportation-Diesel	gallons	5	<u>0.63</u>
Total MMBtu/Ton Recycled Molten Glass			5.12

Notes:

[1] Process energy originally reported in MMBtu.

[2] Cullet coming from MRF not furnace ready; energy calculated from "virgin" system needing 0.11 MMBtu/693 pounds cullet.

Sources:

Personal communication Glass Packaging Institute, February 21, 1991.

Personal communication with John LeBlanc, Owens-Brockway, October 4, 1991.

Figure III-A.22
VIRGIN MOLTEN ALUMINUM PRODUCTION

TABLE III-A-40

MATERIAL AND ENERGY INPUTS: BAUXITE MINING AND PROCESSING

PROCESS			
Material Input		Units /ton	MMBtu
Process Energy	Units	bauxite	Equivalents/ ton bauxite [1]
BAUXITE MINING & PROCESSING			
Fuels:			
Oil	gallons	0.41	0.06
Natural Gas	cubic feet	45	0.05
Other [2]			0.01
Electricity - Purchased	kWh	11	0.11
Total MMBtu/ton Bauxite			0.23

Notes:

[1] Original energy data in Btu/lb bauxite; apportioned to fuel type using breakdown from "Sources and Uses of Energy [Aluminum Industry, 1983]" Table in the Aluminum Association Inc.'s "Energy Conservation and the Aluminum Industry."

[2] Includes gasoline and kerosene.

Numbers may not add up due to rounding.

Sources:

The Aluminum Association, Inc., 1984. "Energy Conservation and the Aluminum Industry."

The Aluminum Association, Inc., 1984. "Energy Content in Aluminum Cans: Historical Performance and Future Potential."

TABLE III-A41
MATERIAL AND ENERGY INPUTS: ALUMINA PRODUCTION

PROCESS				
	Material Input		Units/ton	MMBtu
	Process Energy	Units	alumina	Equivalents/ ton alumina [1]
BAYER PROCESS				
	Bauxite	pounds	4663	
	Lime	pounds	74	
	Caustic Soda	pounds	126	
	Fuels:			
	Oil	gallons	6	0.93
	Natural Gas	cubic feet	9747	10.05
	Coal	tons	0.05	1.17
	Other [2]			0.01
	Electricity - Purchased	kWh	33	0.34
	Electricity - On-Site	kWh	156	1.64
	Total MMBtu/ton Alumina			14.15

Notes:

[1] Original energy data in Btu/lb alumina; apportioned to fuel type using breakdown from "Sources and Uses of Energy [Aluminum Industry, 1983]" Table in the Aluminum Association Inc.'s "Energy Conservation and the Aluminum Industry."

[2] Includes gasoline and kerosene.

TABLE III-A42
MATERIAL AND ENERGY INPUTS: ANODE PRODUCTION

PROCESS				
	Material Input		Units/ton	MMBtu
	Process Energy	Units	anode	Equivalents/ anode
ANODE PRODUCTION [1]				
	Petroleum Coke [2]	pounds	1761	
	Pitch Binder [2]	gallons	47	
	Fuels:			
	Natural Gas	cubic feet	2939	3.03
	Total MMBtu/ton Anode			3.03

Notes:

[1] Anode production split out from Molten Metal production using the following assumptions (per guidance of AAI): 40% of natural gas and LPG consumed in molten metal process are consumed in anode production; all other petroleum coke and pitch are material inputs to anode production; all other energy consumed in molten metal production.

[2] Conversions to determine quantities of materials: 30 MMBtu/ton petroleum coke; 0.16 MMBtu/gallon pitch.

Sources:

The Aluminum Association, Inc., 1984. "Energy Conservation and the Aluminum Industry."

Personal communication with James Plumb, The Aluminum Association, Inc., April 4, 1992.

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

TABLE III-A-43

MATERIAL AND ENERGY INPUTS: REDUCTION OF ALUMINA TO ALUMINUM [1]

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	aluminum	Equivalents/ ton aluminum [3]
CATHODE PRODUCTION [2]			
Anthracite	pounds	40	
Pitch Binder	gallons	0.74	
Electricity - Purchased	kWh	48	0.51
HALL HEROUULT PROCESS			
Alumina	pounds	3860	
Fuels:			
Oil	gallons	0.82	0.12
Natural Gas	cubic feet	1984	2.05
Other [4]			0.03
Electricity - Purchased [5]	kWh	8869	93.13
Electricity - On-Site	kWh	1748	18.35
			114.18

MOLTEN METAL PRODUCTION -- TOTAL ENERGY USE			
Fuels:			
Oil	gallons	0.82	0.12
Natural Gas	cubic feet	1984	2.05
Other [4]			0.03
Electricity - Purchased [5]	kWh	8917	93.63
Electricity - On-Site	kWh	1748	18.35
			114.18
Total MMBtu/ton Molten Aluminum			114.18

Notes:

[1] Includes energy consumption associated with manufacture and use of electrolytes.

[2] Although cathodes are produced outside the aluminum producing facility, only data per ton aluminum were available and are included in this table.

[3] Original energy data in Btu/lb molten metal; apportioned to fuel type using breakdown from "Sources and Uses of Energy [Aluminum Industry, 1983]" Table in the Aluminum Association Inc.'s "Energy Conservation and the Aluminum Industry."

[4] Includes gasoline and kerosene.

[5] 1983 purchased electricity breakdown (in Btu) for molten metal production: 27.1% hydro and 72.9% thermal.

Numbers may not add up due to rounding.

Sources:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

The Aluminum Association, Inc., 1984. "Energy Conservation and the Aluminum Industry."

The Aluminum Association, Inc., 1984. "Energy Content in Aluminum Cans: Historical Performance and Future Potential."

TABLE III-A-44

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN MOLTEN ALUMINUM PRODUCTION

PROCESS		Units/ton	MMBtu
Material Output		molten	Equivalents/ton
Process/Transportation Energy	Units	aluminum	molten aluminum
BAUXITE MINING & PROCESSING			
Bauxite	pounds	8970	
Fuels:			
Oil	gallons	2	0.28
Natural Gas	cubic feet	202	0.21
Other			0.02
Electricity - Purchased	kWh	48	0.51
Transportation-Diesel	gallons	13	1.85
CAUSTIC SODA PRODUCTION [1]			
Caustic Soda	pounds	246	
Electricity - Purchased	kWh	180	1.89
Steam	pounds	1103	1.54
Transportation-Diesel	gallons	0.07	0.01
BAYER PROCESS			
Alumina	pounds	3900	
Fuels:			
Oil	gallons	12	1.81
Natural Gas	cubic feet	19007	19.60
Coal	tons	0.09	2.29
Other			0.02
Electricity - Purchased	kWh	64	0.67
Electricity - On-Site	kWh	305	3.20
Transportation-Diesel	gallons	19	2.59
ANODE PRODUCTION [1]			
Anode	pounds	900	
Fuels:			
Natural Gas	cubic feet	1323	1.36
HALL HEROULT PROCESS			
Molten Aluminum	pounds	2000	
Fuels:			
Oil	gallons	0.82	0.12
Natural Gas	cubic feet	1984	2.05
Other			0.03
Electricity - Purchased	kWh	8917	93.63
Electricity - On-Site	kWh	1748	18.35
Transportation-Diesel [2]	gallons	0.10	0.01
			<u>152.05</u>

TABLE III-A.44 (CONTINUED)

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN MOLTEN ALUMINUM PRODUCTION

PROCESS		Units /ton	MMBtu
Material Output		molten	Equivalents/ton
Process/Transportation Energy	Units	aluminum	molten aluminum
VIRGIN MOLTEN ALUMINUM PRODUCTION - TOTAL ENERGY USE			
Fuels:			
Oil	gallons	15	2.21
Natural Gas	cubic feet	21193	23.21
Coal	tons	0.09	2.29
Other			0.07
Electricity - Purchased	kWh	9210	96.70
Electricity - On-Site	kWh	2052	21.55
Steam	pounds	1103	1.54
Transportation-Diesel	gallons	32	4.46
Total MMBtu/Ton Virgin Molten Aluminum			152.05

Notes:

[1] Refer to Table III-A 10.

[2] Estimate of energy for transporation of cathodes to aluminum smelting facility.

Figure III-A.23

RECYCLED MOLTEN ALUMINUM PRODUCTION

TABLE III-A.45

TOTAL MATERIAL AND ENERGY INPUTS: RECYCLED MOLTEN ALUMINUM PRODUCTION

PROCESS		Units /ton molten aluminum	MMBtu Equivalents/ton molten aluminum [1]
Material Input	Units		
Process/Transportation Energy			
SHREDDING			
Aluminum Scrap [2]	pounds	2222	
Electricity - Purchased	kWh	171	1.80
Transportation-Diesel	gallons	5	0.69
DELAQUERING AND MELTING			
Fuels:			
Natural Gas	cubic feet	6324	6.52
			9.01

RECYCLED MOLTEN ALUMINUM PRODUCTION - TOTAL ENERGY USE			
Fuels:			
Natural Gas	cubic feet	6324	6.52
Electricity - Purchased	kWh	171	1.80
Transportation-Diesel	gallons	5	0.69
			9.01
Total MMBtu/Ton Recycled Molten Aluminum			9.01

Notes:

[1] Process energy originally reported in MMBtu.

[2] 1.11 tons aluminum scrap/ton molten aluminum.

Sources:

A.D. Little, 1986. "Aluminum Industry Scoping Study," prepared for Center for Metals Production, CMP Report No. 86-2.
 Written communication with Mark Hauser, ALCOA, September 1991.

Figure III-A.24

MOLTEN STEEL PRODUCTION -
BASIC OXYGEN FURNACE (10% POST-CONSUMER CONTENT)

TABLE III-A46

MATERIAL AND ENERGY INPUTS: IRON ORE MINING - SUPPLY AS RAW FEED AND
SINTER PLANT FEED

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	iron ore	Equivalents/ ton iron ore
IRON ORE MINING			
Fuels:			
Diesel	gallons	0.16	0.02
Gasoline	gallons	0.01	0.001
Natural Gas	cubic feet	0.14	0.0001
Electricity - Purchased	kWh	25	0.26
Total MMBtu/Ton Raw Iron Ore Feed			0.29

Sources:

Battelle Columbus Laboratory, "Potential for Energy Conservation in the Steel Industry," prepared for Federal Energy Administration, May 30, 1975, provided by Gregory Crawford, Steel Can Recycling Institute.

TABLE III-A47

MATERIAL AND ENERGY INPUTS: IRON ORE MINING & BENEFICIATION

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	Iron ore	Equivalents/ ton iron ore
IRON ORE MINING			
Fuels:			
Diesel	gallons	0.63	0.09
Gasoline	gallons	0.04	0.005
Electricity - Purchased	kWh	39	0.41
BENEFICIATION [1]			
Ball Rods & Liners	pounds	20	
Electricity - Purchased	kWh	67	0.71
			1.21

IRON ORE MINING AND BENEFICIATION - TOTAL ENERGY INPUTS

Fuels:			
Diesel	gallons	1	0.09
Gasoline	gallons	0.04	0.005
Electricity - Purchased	kWh	106	1.11
Total MMBtu/ton Iron Ore			1.21

Notes:

[1] Includes electricity for crushing, grinding, and concentrating.

Source:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

TABLE III-A.48
MATERIAL AND ENERGY INPUTS: IRON ORE PELLET PRODUCTION

PROCESS				
Material Input			Units /ton	MMBtu
Process Energy		Units	pellets	Equivalents/ ton pellets
PELLETIZING				
Iron Ore Concentrate		pounds	1984	
Bentonite		pounds	16	
Fuels:				
Oil		gallons	1.5	0.22
Natural Gas		cubic feet	275	0.28
Electricity - Purchased		kWh	5	0.05
Total MMBtu/ton Pellets				0.56

Source:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

TABLE III-A.49
MATERIAL AND ENERGY INPUTS: LIME PRODUCTION

PROCESS			MMBtu
Material Input		Units /ton	Equivalents/
Process Energy	Units	lime	ton lime
LIME PRODUCTION			
Limestone	pounds	3750	
Fuels:			
Natural Gas	cubic feet	2350	2.42
Coal	tons	0.09	2.35
Electricity - Purchased	kWh	28	0.29
Total MMBtu/ton Lime			5.07

Notes:

[1] Other fuels not specified.

Sources:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines, citing: "SIC 1422 Crushed and Broken Limestone," U.S. Department of Commerce, Bureau of the Census, 1970; Industrial Chemicals, Faith, W. L., et al, 1965; "A Comparison of Modern Lime Calcining Systems," Schwarzkopf, F., 1970.

TABLE III-A.50
MATERIAL AND ENERGY INPUTS: COAL MINING

PROCESS			MMBtu
Material Input		Units/ton	Equivalents/
Process Energy	Units	coke	ton coke
COAL MINING			
Fuels:			
Other [1]			0.36
Total MMBtu/ton Coke			0.36

Notes:
[1] Fuel source not specified.

TABLE III-A.51
MATERIAL AND ENERGY INPUTS: COKE PRODUCTION

PROCESS			MMBtu
Material Input		Units/ton	Equivalents/
Process Energy	Units	coke	ton coke
Coproducts			
COKE PRODUCTION			
Coal	pounds	2900	
Fuels:			
Coke Oven Gas [1]	cubic feet	6960	3.48
Electricity - Purchased	kWh	33	0.35
Steam [2]	pounds	1000	1.00
Tar	gallons	13	-2.09
Light oil	gallons	3.6	-0.45
Coke Breeze	pounds	140	-1.47
			0.82

COKE PRODUCTION - TOTAL ENERGY USE

Fuels:			
Coke Oven Gas	cubic feet	6960	3.48
Electricity - Purchased	kWh	33	0.35
Steam [1]	pounds	1000	1.00
Coproducts			-4.01
Total MMBtu/ton Coke			0.82

Breakdown of Energy Sources - Byproducts and Purchased [3]

Byproducts: Energy from Coke Oven Gas	3.48
Purchased	-2.13

Notes:
[1] Fuels used in coke production are underfiring fuels, primarily coke oven gas, with energy intensity (Btu conversion factor) of 500 Btu/cubic foot.
[2] Energy value of steel plant produced steam from coal fired and waste heat boilers equals 1000 Btu/pound.
[3] Energy value of byproducts used elsewhere in plant: Coke Oven Gas - 7.61 MMBtu/ton coke

Sources For Tables III-A.50 and III-A.51:
Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

TABLE III-A.52

MATERIAL AND ENERGY INPUTS: IRON ORE SINTER PRODUCTION

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	sinter	Equivalents/ ton sinter
SINTER PRODUCTION			
Ore Fines	pounds	1220	
Limestone	pounds	98	
Returns	pounds	534	
Flue Dust and Fines	pounds	286	
Mill Scale	pounds	244	
Fuels:			
Natural Gas	cubic feet	150	0.15
Coke Breeze	tons	0.07	1.55
Electricity - Purchased	kWh	30	0.32
Total MMBtu/ton Iron Ore Sinter			2.02

Notes:

[1] Coke breeze, from the production of coke, is an energy input into sinter production, with an energy intensity of 21 MMBtu/ton.

Sources:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

TABLE III-A.53

MATERIAL AND ENERGY INPUTS: PIG IRON (HOT METAL) PRODUCTION

PROCESS			MMBtu
Material Input		Units/ton	Equivalents/
Process Energy	Units	pig iron	ton pig iron
PIG IRON PRODUCTION			
Coke [1]	pounds	1017	
Iron Ore	pounds	101	
Iron Ore Pellets	pounds	2467	
Sinter	pounds	498	
Limestone	pounds	500	
Mill Scale	pounds	100	
Iron Scrap	pounds	54	
Refractories	pounds	3	
Oxygen	cubic feet	700	
Fuels:			
Oil	gallons	3	0.45
Natural Gas	cubic feet	1049	1.08
Coke [1]	pounds	1017	13.22
Tar and Pitch	gallons	0.43	0.07
Coke Oven Gas	cubic feet	407	0.20
Blast Furnace Gas	cubic feet	14240	1.35
Electricity - Purchased	kWh	41	0.43
Steam [2]	pounds	1200	1.20
Total MMBtu/ton Pig Iron			18.90
Breakdown of Energy Sources - Byproducts and Purchased [3]			
Byproducts: Energy from Tar & Pitch			0.07
Energy from Coke Oven Gas			0.20
Energy from Blast Furnace Gas			1.35
Total byproducts energy			1.62
Purchased			16.38

Notes:

[1] Coke is both a material and energy input. Coke is the primary fuel in the production of pig iron, as well as a reducing agent in the furnace; energy intensity conversion equals 25.99 MMBtu/ton coke.

[2] Energy value of steel plant produced steam from coal fired and waste heat boilers equals 1000 Btu/pound.

[3] Energy value of byproducts used elsewhere in plant: Blast Furnace Gas - 3.91 MMBtu/ton pig iron

Source:

Personal communication with Gregory Crawford, Steel Can Recycling Institute, April 13, 1992: material inputs and fuel data based on 1990 AISI statistics; electricity and steam use based on private communication, all provided by Clyde Davis, U.S. Steel Technical Center.

TABLE III-A.54

MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION – BOF
10% POST-CONSUMER CONTENT [1]

PROCESS			
Material Input		Units/ton	MMBtu
Process Energy	Units	molten steel	Equivalents/ ton molten steel
SCRAP PROCESSING [2]			
Steel Scrap	pounds	231	
Fuels:			
Other			0.08
BOF MOLTEN STEEL PRODUCTION			
Pig Iron	pounds	2079	
Scrap	pounds	231	
Limestone	pounds	17	
Lime	pounds	114	
Iron Ore Pellets	pounds	6	
Desulf Reagents			
Spar	pounds	2	
Ferromanganese	pounds	22	
Ferrosilicon	pounds	2	
Aluminum	pounds	1	
Mill Scale	pounds	16	
Refractories	pounds	4	
Oxygen	cubic feet	193	
Fuels:			
Natural Gas	cubic feet	272	0.28
Electricity - Purchased	kWh	30	0.32
			0.68

TOTAL ENERGY USE – BOF MOLTEN STEEL PRODUCTION			
Fuels:			
Natural Gas	cubic feet	272	0.28
Other			0.08
Electricity - Purchased	kWh	30	0.32
			0.68
Total MMBtu/Ton Molten Steel			0.68

Notes:

[1] Calculated as 10% breakdown between scrap and pig iron composition.

[2] Scrap processing energy for post-consumer portion of scrap input (231 pounds); based on Sparrow estimate of 0.7 MMBtu/ton for ferrous scrap.

Source:

Personal communication with Gregory Crawford, Steel Can Recycling Institute, April 13, 1992: material inputs and fuel data based on 1990 AISI statistics; electricity use based on private communication, all provided by Clyde Davis, U.S. Steel Technical Center.

TABLE III-A.55

**TOTAL MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION --
BOF (10% POST-CONSUMER CONTENT)**

PROCESS				
	Material Output		Units/ton	MMBtu
	Process/Transportation Energy		molten	Equivalents/ton
	Coproducts	Units	steel	molten steel
IRON ORE MINING				
	Iron Ore Raw/Sinter Feed [1]	pounds	421	
	Fuels:			
	Diesel	gallons	0.03	0.005
	Gasoline	gallons	0.002	0.0003
	Natural Gas	cubic feet	0.03	0.0000
	Electricity - Purchased	kWh	5.26	0.06
	Transportation-Diesel	gallons	0.53	0.07
IRON ORE MINING & BENEFICIATION				
	Iron Ore Concentrate [2]	pounds	2550	
	Fuels:			
	Diesel	gallons	0.80	0.11
	Gasoline	gallons	0.05	0.006
	Electricity - Purchased	kWh	135	1.42
	Transportation-Diesel	gallons	3.20	0.44
IRON ORE PELLET PRODUCTION				
	Pellets		2570	
	Fuels:			
	Oil	gallons	2	0.29
	Natural Gas	cubic feet	353	0.36
	Electricity - Purchased	kWh	6	0.07
LIMESTONE MINING & PROCESSING [3]				
	Limestone	pounds	776	
	Fuels:			
	Diesel	gallons	0.06	0.008
	Natural Gas	cubic feet	5	0.005
	Other			0.007
	Electricity - Purchased	kWh	1	0.01
	Transportation-Diesel [4]	gallons	0.12	0.02
LIME PRODUCTION				
	Lime	pounds	114	
	Fuels:			
	Natural Gas	cubic feet	134	0.14
	Coal	tons	0.01	0.13
	Electricity - Purchased	kWh	2	0.02
	Transportation-Diesel	gallons	0.03	0.00
COAL MINING				
	Coal	pounds	1533	
	Fuels:			
	Other			0.28
	Transportation-Diesel	gallons	1.06	0.15
COKE PRODUCTION				
	Coke	pounds	1057	
	Fuels:			
	Other			1.84
	Electricity - Purchased	kWh	17	0.18
	Steam	pounds	529	0.53
	Coproducts			-2.12

TABLE III-A.55 (CONTINUED)

TOTAL MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION --
BOF (10% POST-CONSUMER CONTENT)

PROCESS

Material Output Process/Transportation Energy <i>Coproducts</i>	Units	Units/ton molten steel	MMBtu Equivalents/ton molten steel
IRON ORE SINTER PRODUCTION			
Sinter	pounds	518	
Fuels:			
Natural Gas	cubic feet	39	0.04
Coke Breeze	tons	0.02	0.61
Electricity - Purchased	kWh	8	0.08
PIG IRON PRODUCTION			
Pig Iron (Hot Metal)	pounds	2079	
Fuels:			
Oil	gallons	3	0.47
Natural Gas	cubic feet	1090	1.12
Coke	tons	0.53	13.74
Other			1.69
Electricity - Purchased	kWh	43	0.45
Steam	pounds	1247	1.25
STEEL PRODUCTION			
Molten Steel	pounds	2000	
Fuels:			
Natural Gas	cubic feet	272	0.28
Other			0.08
Electricity - Purchased	kWh	30	0.32
Transportation-Diesel [5]	gallons	0.52	0.07
			<u>24.23</u>

MOLTEN STEEL PRODUCTION -- TOTAL ENERGY USE

Fuels:			
Oil	gallons	6	0.76
Diesel	gallons	1	0.12
Gasoline	gallons	0.05	0.01
Natural Gas	cubic feet	1893	1.95
Coal	tons	0.01	0.13
Coke	tons	0.53	13.74
Coke Breeze	tons	0.02	0.61
Other			3.89
Electricity - Purchased	kWh	243	2.60
Steam	pounds	1776	1.78
Transportation-Diesel	gallons	5	0.76
<i>Coproducts</i>			<u>-2.12</u>
Total MMBtu/ton Molten Steel -- BOF (10% Post-Consumer Content)			24.23

Breakdown of Energy Sources - Byproducts and Purchased

Byproducts: Energy from Coke Oven Gas	3.25
Energy from Blast Furnace Gas	1.41
Energy from Tar & Pitch	0.07
Total byproducts energy	4.72
Purchased:	19.50

TABLE III-A.55 (CONTINUED)

**TOTAL MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION –
BOF (10% POST-CONSUMER CONTENT)**

Notes:

- [1] Includes iron ore used directly as fines, and in sinter production.
- [2] Iron ore used in pellet production.
- [3] Refer to Table III-A.35; limestone to sinter plant, blast furnace, BOF and as feed for lime.
- [4] Transportation energy only of limestone used as limestone, not that used for lime production.
- [5] Transportation energy of scrap from MMBtu/ton calculated in recycled system.

Figure III-A.25

**MOLTEN STEEL PRODUCTION -
ELECTRIC ARC FURNACE (100% POST-CONSUMER CONTENT)**

TABLE III-A-56

TOTAL MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION --

EAF (100% POST-CONSUMER CONTENT)

PROCESS		Units/ton molten steel	MMBtu Equivalents/ton molten steel
Material Input	Units		
Process/Transportation Energy			
LIMESTONE MINING & PROCESSING [1]			
Limestone	pounds	135	
Fuels:			
Diesel	gallons	0.01	0.0014
Natural Gas	cubic feet	0.83	0.0009
Other			0.0012
Electricity - Purchased	kWh	0.25	0.0026
LIME PRODUCTION [2]			
Lime	pounds	72	
Fuels:			
Natural Gas	cubic feet	85	0.09
Coal	tons	0.003	0.08
Electricity - Purchased	kWh	1	0.01
Transportation-Diesel [3]	gallons	0.02	0.003
SCRAP PROCESSING [4]			
Merchant Steel Scrap	pounds	1986	
Transportation-Diesel	gallons	4	0.62
STEEL PRODUCTION (additional inputs)			
Iron Scrap	pounds	102	
Fluorspar	pounds	2	
Electrodes	pounds	5.9	
Refractories	pounds	16.2	
Ferromanganese	pounds	8	
Ferrosilicon	pounds	6	
Aluminum	pounds	2	
Oxygen	cubic feet	812.5	
Fuels:			
Natural Gas	cubic feet	100	0.10
Electricity - Purchased	kWh	393	4.13
			5.04

TABLE III-A.56 (CONTINUED)

TOTAL MATERIAL AND ENERGY INPUTS: MOLTEN STEEL PRODUCTION -

EAF (100% POST-CONSUMER CONTENT)

PROCESS			Units/ton	MMBtu
Material Input			molten	Equivalents/ton
Process/Transportation Energy	Units		steel	molten steel
RECYCLED MOLTEN STEEL PRODUCTION - TOTAL ENERGY USE				
Fuels:				
Diesel	gallons		0.01	0.001
Natural Gas	cubic feet		185	0.19
Coal	tons		0.003	0.08
Other				0.001
Electricity - Purchased	kWh		394	4.14
Transportation-Diesel	gallons		4	0.62
Total MMBtu/Ton EAF-100% Post-Consumer Content Molten Steel				5.04

Notes:

- [1] Refer to Table III-A.35; included as energy to mine limestone for lime production.
- [2] Refer to Table III-A.47.
- [3] Lime transportation energy calculated from BOF transport table.
- [4] Transportation of merchant scrap as calculated in Table III-B.8.

Sources:

Based on IISI Statistics, 1989, provided by Clyde Davis of U.S. Steel Technical Center, through personal communication with Gregory Crawford, Steel Can Recycling Institute.

Figure III-A.26

VIRGIN AGGREGATE ROADBASE PRODUCTION

TABLE III-A.57

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN AGGREGATE ROAD BASE PRODUCTION [1]

PROCESS	Material Input	Units	Units/ton aggregate	MMBtu Equivalents/ton aggregate [2]
	Process Energy			
MINING OF ROCK				
	Electricity - Purchased	kWh	1.5	0.016
PRIMARY CRUSHING				
	Electricity - Purchased	kWh	0.2	0.002
CONVEYING				
	Electricity - Purchased	kWh	1.5	0.016
SCREENING				
	Electricity - Purchased	kWh	0.2	0.002
SECONDARY & TERTIARY CRUSHING				
	Electricity - Purchased	kWh	1.0	0.010
SCREENING				
	Electricity - Purchased	kWh	0.4	0.004
				0.050

VIRGIN AGGREGATE ROAD BASE PRODUCTION - TOTAL ENERGY USE				
	Electricity - Purchased	kWh	4.8	0.050
Total MMBtu/Ton Virgin Aggregate				0.050

Notes:

[1] The pumping and washing & dewatering steps have been omitted as inappropriate in the production of gravel to be used as road aggregate (per personal communication with Brian Doyle, Brian W. Doyle Engineering, March 31, 1992).

[2] Process energy originally reported in MMBtu.

Sources:

Battelle Columbus Laboratories, 1975. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing," prepared for U.S. Bureau of Mines.

Figure III-A.27

Virgin Lubricating Oil Base Stock Production

TABLE III-A-58

MATERIAL AND ENERGY INPUTS: ONSHORE OIL EXTRACTION & DESALTING (per bbl)

PROCESS	Material Input	Units	Units/ton crude oil	MMBtus/MM Btus crude oil produced [1]	MMBtu Equivalents/ bbl crude oil [2]
	Process Energy				
DEVELOPMENTAL DRILLING					
	Fuels:				
	Diesel			7.60E-03	0.04
CRUDE OIL EXTRACTION					
	Electricity - Purchased	kWh	4	7.16E-03	0.04
CRUDE OIL DESALTING					
	Crude Oil	barrels	1		
	Fuels:				
	Other [3]				0.00003
	Electricity - Purchased	kWh	0.09		0.001
					0.09

PRIMARY ONSHORE OIL EXTRACTION & DESALTING - TOTAL ENERGY USE					
	Crude Oil	barrels	1		
	Fuels:				
	Diesel				0.04
	Other [3]				0.00003
	Electricity	kWh	4.05		0.04
					0.09
	Total MMBtu/bbl Desalted Crude Oil				0.09

Notes:

[1] Original energy data in MMBtu used/MMBtu crude oil produced.

[2] Using conversion factor of 138,100 Btu/gallon crude oil, and 42 gallons/bbl.

[3] Process fuel not specified.

Numbers may not add up due to rounding.

Sources:

U.S. Department of Energy, "Energy Technology Characterizations Handbook," 1983, 106-107.

Gaines & Wilsky, "Energy and Materials Flows in Petroleum Refining," U.S. Department of Energy, 1981, pp. 63-65.

TABLE III-A.59

MATERIAL AND ENERGY INPUTS: CRUDE OIL PROCESSING (per bbl)

PROCESS			MMBtu
Material Input		Units/barrel	Equivalents/bbl
Process Energy		distilled	distilled
Coproducts	Units	crude oil [1]	crude oil
ATMOSPHERIC DISTILLATION			
Desalted Crude Oil	barrels	4	
Fuels:			
Other [2]			0.35
Electricity - Purchased	kWh	3	0.03
Steam	pounds	80	0.11
VACUUM DISTILLATION			
Fuels:			
Other [2]			0.25
Electricity - Purchased	kWh	1	0.01
Steam	pounds	106	0.15
Coproducts	barrels	3	-0.67
			0.22
TOTAL ENERGY USE - ATMOSPHERIC & VACUUM DISTILLATION OF CRUDE OIL			
Desalted Crude Oil	barrels		
Fuels:			
Other [2]			0.60
Electricity - Purchased	kWh	4	0.04
Steam	pounds	186	0.26
Coproducts	barrels	3	-0.67
			0.22
Total MMBtu/bbl Distilled Oil			0.22

Notes:

[1] Original energy data per barrel of feed; 25% yield of lube oil feedstock from distillation processes, remaining 75% is useful coproducts.

[2] Process fuel not specified.

Numbers may not add up due to rounding.

Sources:

Gaines & Wolsky, "Energy and Materials Flows in Petroleum Refining," U.S. Department of Energy, 1981, 63-65.

David J. McKeagan and Associates, "Market Potential for a Used Oil Rerefinery at CIBRO, Albany."

TABLE III-A.60

MATERIAL AND ENERGY INPUTS: SOLVENT EXTRACTION

PROCESS

Material Input			MMBtu
Process Energy		Units/barrel	Equivalents/bbl
<i>Coproducts</i>	<i>Units</i>	<i>produced [1]</i>	<i>produced</i>
SOLVENT EXTRACTION			
Lube Oil Feedstock	barrels	1.67	
Fuels:			
Other [2]			0.19
Electricity - Purchased	kWh	3.0	0.03
Steam	pounds	-6	-0.01
<i>Coproducts</i>	<i>barrels</i>	<i>0.67</i>	<i>-0.08</i>
Total MMBtu/bbl Produced			0.13

Notes:

[1] Original energy data per barrel of feed; 60% yield for solvent extraction.

[2] Process fuel not specified.

Numbers may not add up due to rounding.

Sources:

David J. McKeagan and Associates, "Market Potential for a Used Oil Rerefinery at CIBRO, Albany."

TABLE III-A.61

MATERIAL AND ENERGY INPUTS: HYDROCRACKING

PROCESS

Material Input			MMBtu
Process Energy		Units/barrel	Equivalents/bbl
<i>Coproducts</i>	<i>Units</i>	<i>hydrocracked [1]</i>	<i>hydrocracked</i>
HYDROCRACKING			
Lube Oil Feedstock	barrels	2.00	
Fuels:			
Other [2]			0.27
Electricity - Purchased	kWh	28	0.29
Steam	pounds	18	0.02
<i>Coproducts</i>	<i>barrels</i>	<i>1.00</i>	<i>-0.28</i>
Total MMBtu/bbl Produced			0.31

Notes:

[1] Original energy data per barrel of feed; 50% yield for hydrocracking.

[2] Process fuel not specified.

Numbers may not add up due to rounding.

Sources:

David J. McKeagan and Associates, "Market Potential for a Used Oil Rerefinery at CIBRO, Albany."

TABLE III-A.62
MATERIAL AND ENERGY INPUTS: LUBE DEWAXING

PROCESS			
Material Input			MMBtu
Process Energy		Units/barrel	Equivalents/bbl
<i>Coproducts</i>	Units	produced [1]	produced
DEWAXING			
Solvent Extracted Oil [2]	barrels	1.49	
Electricity - Purchased	kWh	19	0.20
Steam	pounds	297	0.42
<i>Coproducts</i>	<i>barrels</i>	<i>0.49</i>	<i>-0.20</i>
Total MMBtu/bbl Produced			0.42

Notes:

- [1] Original energy data per barrel of feed; 67% yield for dewaxing process.
 [2] Dewaxing follows either solvent extraction or hydrotreating; process energy the same for oil from hydrocracking or solvent extraction.
 Numbers may not add up due to rounding.

Sources:

David J. McKeagan and Associates, "Market Potential for a Used Oil Rerefinery at CIBRO, Albany."

TABLE III-A.63
MATERIAL AND ENERGY INPUTS: LUBE HYDROFINISHING

PROCESS			
Material Input			MMBtu
Process Energy		Units/barrel	Equivalents/bbl
	Units	hydrofinished [1]	hydrofinished
HYDROFINISHING			
Dewaxed Oil [2]	barrels	1.00	
Fuels:			
Other [3]			0.02
Electricity - Purchased	kWh	1	0.01
Steam	pounds	18	0.03
Total MMBtu/bbl Produced			0.03

Notes:

- [1] Original energy data per barrel of feed; 100% yield for hydrofinishing.
 [2] Process energy the same for dewaxed oil from hydrocracking or solvent extraction.
 [3] Process fuel not specified.
 Numbers may not add up due to rounding.

Sources:

David J. McKeagan and Associates, "Market Potential for a Used Oil Rerefinery at CIBRO, Albany."

TABLE III-A.64

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN LUBRICATING OIL BASE STOCK

PROCESS

Material Output			MMBtu
Process/Transportation Energy		Units/bbl	Equivalents/bbl
Coproducts	Units	lube stock	lube stock
CRUDE OIL EXTRACTION AND DESALTING			
Desalted Crude Oil	barrels	10.95	
Fuels:			
Diesel			0.48
Other			0.0003
Electricity - Purchased	kWh	44	0.46
Transportation - Diesel [1]	gallons	1	0.12
Transportation - Natural Gas [1]	cubic feet	99	0.10
ATMOSPHERIC & VACUUM DISTILLATION			
Lube Oil Feedstock	barrels	2.74	
Fuels:			
Other			1.64
Electricity - Purchased	kWh	11	0.11
Steam	pounds	509	0.71
Coproducts	barrels	8.21	-1.85
SOLVENT EXTRACTION [2]			
Solvent Extracted Oil	barrels	0.75	
Fuels:			
Other			0.14
Electricity - Purchased	kWh	2	0.02
Steam	pounds	4	-0.01
Coproducts	barrels	0.50	-0.06
HYDROCRACKING [2]			
Hydrocracked Oil	barrels	0.75	
Fuels:			
Other			0.20
Electricity - Purchased	kWh	21	0.22
Steam	pounds	13	0.02
Coproducts	barrels	0.75	-0.21
DEWAXING			
Dewaxed Oil	barrels	1.00	
Electricity - Purchased	kWh	19	0.20
Steam	pounds	297	0.42
Coproducts	barrels	0.49	-0.20
LUBE HYDROFINISHING			
Desalted Crude Oil	barrels	1.00	
Fuels:			
Other			0.02
Electricity - Purchased	kWh	1	0.01
Steam	pounds	18	0.03
			2.58

TABLE III-A.64 (CONTINUED)

TOTAL MATERIAL AND ENERGY INPUTS: VIRGIN LUBRICATING OIL BASE STOCK

PROCESS

Material Output Process Energy <i>Coproducts</i>	Units	Units/bbl lube stock	MMBtu Equivalents/bbl lube stock
TOTAL ENERGY USE - VIRGIN LUBRICATING OIL BASE STOCK			
Desalted Crude Oil	barrels	18.95	
Fuels:			
Diesel	gallons		0.48
Other			2.00
Electricity - Purchased	kWh	99	1.04
Steam	pounds	833	1.17
Transportation - Diesel [1]	gallons	1	0.12
Transportation - Natural Gas [1]	cubic feet	99	0.10
<i>Coproducts</i>	<i>barrels</i>	9.94	-2.32
Total MMBtu/bbl Virgin Base Stock			2.58

Notes:

[1] Transportation energy requirement calculated from virgin lube oil transport system using 0.1533 ton/bbl conversion (306.6 pounds/bbl); only the transportation cost of one bbl of input are included because the remaining 9.95 bbl result in useful byproducts; Transportation energy disaggregated between diesel (ship) and natural gas (pipeline).

[2] Assume that 50% lube produced via solvent extraction step, and 50% via hydrocracking step.

Figure III-A.28

REREFINED LUBRICATING OIL BASE STOCK PRODUCTION

TABLE III-A.65

TOTAL MATERIAL AND ENERGY INPUTS: REREFINED LUBRICATING OIL BASE STOCK

PROCESS		MMBtu	
Material Output		Units/bbl	Equivalents/bbl
Process/Transportation Energy	Units	lube stock [1]	lube stock
ATMOSPHERIC & VACUUM DISTILLATION [2]			
Fuels:			
Other			0.24
Electricity - Purchased	kWh	2	0.02
Steam	pounds	74	0.10
Transportation-Diesel [3]	gallons	2	0.25
LUBE HYDROFINISHING [4]			
Rerefined Oil	barrels	1.80	
Fuels:			
Other			0.02
Electricity - Purchased	kWh	1	0.01
Steam	pounds	18	0.03
			<u>0.67</u>

USED OIL REREFINING - TOTAL ENERGY USE

Fuels:			
Other			0.26
Electricity - Purchased	kWh	3	0.03
Steam	pounds	92	0.13
Transportation-Diesel	gallons	2	<u>0.25</u>
Total MMBtu/bbl Rerefined Lube Oil			0.67

Notes:

[1] Process energy requirements assumed to be the same as for virgin crude oil; rerrefining energies calculated needing 1.59 bbl feed/bbl rerrefined lube produced.

[2] Refer to Table III-A.57.

[3] Transportation energy requirement calculated from recycled transport system using 0.1533 ton/bbl conversion.

[4] Refer to Table III-A.61.

Numbers may not add up due to rounding.

Sources:

Gaines & Wolsky, "Energy and Materials Flows in Petroleum Refining," U.S. Department of Energy, 1981, 63-65.

David J. McKeagan and Associates, "Market Potential for a Used Oil Rerrefinery at CIBRO, Albany."

APPENDIX III-B
TRANSPORTATION ANALYSIS TABLES

TABLE III-B.1
TRANSPORT OF RAW MATERIALS FOR VIRGIN LINERBOARD PRODUCTION

ORIGIN			FINAL DESTINATION								
LOCATION	% US Production	% Supply for Destination	LOCATION	% US Production	Normalized % Production	% Traveling this Route	Approximate Distance (mi.)	Weighted Miles	Mode	Btu/Ton-Mile [2]	MMBtu/Ton
1. ROUNDWOOD [1]											
Forest		100.0	Mill		100.0	100.0	100	100	Truck	2500	0.25

Notes:

[1] Assume all mills supplied by forests within one hundred miles.

[2] Fuel efficiency, Source PP-1.

TABLE III-B.2
TRANSPORT OF RAW MATERIALS FOR VIRGIN NEWSPRINT PRODUCTION

ORIGIN			FINAL DESTINATION			% Traveling this Route	Approximate Distance (mi.)	Weighted Miles	Mode	Btu/ Ton-Mile [2]	MMBtu/Ton
LOCATION	% US Production	% Supply for Destination	LOCATION	% US Pro- duction	Normalized % Production						
1. ROUNDWOOD [1]											
Forest		100.0	Mill		100.0	100.0	100	100	Truck	2500	0.25

Notes:

[1] Assume all mills supplied by forests within one hundred miles.

[2] Fuel efficiency, Source PP-1.

TABLE III-B.3
TRANSPORT OF RAW MATERIALS FOR VIRGIN OFFICE PAPER PRODUCTION

ORIGIN			FINAL DESTINATION			% Travelling this Route	Approximate Distance (mi.)	Weighted Miles	Mode	Btu/ Ton-Mile [2]	MMBtu/Ton
LOCATION	% US Production	% Supply for Destination	LOCATION	% US Pro- duction	Normalized % Production						
1. ROUNDWOOD [1]											
Forest		100.0	Mill		100.0	100.0	100	100	Truck	2500	0.25
2. CHLORINE & CAUSTIC SODA [2]											
Region surrounding mill		100.0	Mill		100.0	100.0	100	100	Rail	750	0.08

Notes:

- [1] Assume all mills supplied by forests within one hundred miles.
[2] Assumed caustic soda & chlorine acquired within 100 mile radius of mill, and transported by rail.
[3] Fuel efficiency, Source PP-1.

TABLE III-B.4
TRANSPORT OF RAW MATERIALS FOR VIRGIN COATED BOXBOARD PRODUCTION

ORIGIN			FINAL DESTINATION								
LOCATION	% US Production	% Supply for Destination	LOCATION	% US Production	Normalized % Production	% Traveling this Route	Approximate Distance (mi.)	Weighted Miles	Mode	Btu/Ton-Mile [2]	MMBtu/Ton
1. ROUNDWOOD [1]											
Forest		100.0	Mill		100.0	100.0	100	100	Truck	2500	0.25

Notes:

- [1] Assume all mills supplied by forests within one hundred miles.
[2] Fuel efficiency, Source PP-1.

TABLE III-B.5
TRANSPORT OF RAW MATERIALS FOR VIRGIN PLASTIC RESINS PRODUCTION

ORIGIN			FINAL DESTINATION [1,2]			% Traveling this Route	Approximate Distance (mi.)	Weighted Miles	Mode	Btu/ Ton-Mile [8] MMBtu/Ton		
LOCATION	% US Imports or Production	% Supply for Destination	LOCATION	% US Production	Normalized % Production							
1 CRUDE OIL [3,4]												
1.a	Gulf Coast		56.0	Gulf Coast	-	85.4 [5]	47.8	100	48	Pipeline	2085	0.10
	Middle East	30.4	17.1	Gulf Coast			14.6	16,000	2333	Ship	225	0.52
	Africa	22.0	12.4	Gulf Coast			10.6	7500	793	Ship	225	0.18
	South America	13.6	7.7	Gulf Coast			6.5	2,200	144	Ship	225	0.03
	Mexico	12.3	6.9	Gulf Coast			5.9	700	41	Ship	225	0.01
1.b.	Gulf Coast		100.0	Gulf Coast	40.7	59.5	59.5	100 [6]	60	Pipeline	2085	0.12
	Middle East	30.4	58.0	Northern NJ	6.6	9.6	5.6	15,000	834	Ship	225	0.19
	Africa	22.0	42.0	Northern NJ			4.0	6,500	262	Ship	225	0.06
	Gulf Coast		100.0	Illinois	6.0	8.8	8.8	775	68	Pipeline	2085	0.14
	Gulf Coast		100.0	Ohio	5.3	7.7	7.7	1025	79	Pipeline	2085	0.17
	California		50.0	California	3.4	5.0	2.5	100 [6]	3	Pipeline	2085	0.01
	Alaska		50.0	California			2.5	1,400	35	Ship	225	0.01
	Gulf Coast		100.0	Pennsylvania	3.2	4.7	4.7	1075	51	Pipeline	2085	0.11
	Gulf Coast		100.0	Tennessee	3.2	4.7	4.7	600	28	Pipeline	2085	0.06
TOTAL MMBtu/TON											1.70	
2 NATURAL GAS [7]												
	Gulf Coast	62.7	100.0	Gulf Coast	40.7	59.5	59.5	100 [6]	60	Pipeline	2085	0.12
	Gulf Coast	62.7	100.0	Northern NJ	6.6	9.6	9.6	1300	125	Pipeline	2085	0.26
	Gulf Coast	62.7	100.0	Illinois	6.0	8.8	8.8	775	68	Pipeline	2085	0.14
	Gulf Coast	62.7	100.0	Ohio	5.3	7.7	7.7	1025	79	Pipeline	2085	0.17
	West Texas		100.0	California	3.4	5.0	5.0	900	45	Pipeline	2085	0.09
	Gulf Coast	62.7	100.0	Pennsylvania	3.2	4.7	4.7	1075	51	Pipeline	2085	0.11
	Gulf Coast	62.7	100.0	Tennessee	3.2	4.7	4.7	600	28	Pipeline	2085	0.06
TOTAL MMBtu/TON											0.95	

TABLE III-B.5 (CONTINUED)
TRANSPORT OF RAW MATERIALS FOR VIRGIN PLASTIC RESINS PRODUCTION

Notes

- [1] "Final Desinations" are resin producers; Resin producers may be integrated with refinery (therefore equivalent of final destination) or may be separate from refinery. Because all the resin producing states are also significant refining areas, it is assumed that refining of raw materials into feedstock takes place in resin producing state; additional assumption that when raw materials (oil, natural gas) are obtained from out of state, transport of feedstock material from refinery to olefins plant is negligible compared to transport of raw material to the resin producing state.
- [2] Location of resin producers, Source P-1; percentages based on "Value of Shipments."
- [3] Source P-2; in 1989 imports accounted for approximately 44% of petroleum demand.
- [4] Because Gulf Coast is gate for crude oil imports into United States, part "a" calculates transportation of oil to Gulf Coast, apportioned 56% domestic and 44% imported; part "b" is transport of crude to resin producing states.
- [5] Sum of normalized resin production percentages of areas that acquire crude oil from Gulf Coast (GC, IL, OH, PA, TN).
- [6] Because extraction, refining and feedstock production occur within the state, transportation between raw material or feedstock producer and olefins plant is 100 miles ("in-state rule").
- [7] Source P-3; in 1989 imports accounted for 6.7% of natural gas consumption.
- [8] Fuel efficiency for ship, Source P-4; fuel efficiency for pipeline calculated from Source P-5.

TABLE III-B.6
TRANSPORT OF RAW MATERIALS FOR VIRGIN MOLTEN GLASS PRODUCTION

ORIGIN			FINAL DESTINATION					Approximate Distance (mi.)	Weighted Miles	Mode	Btu/ Ton-Mile [8]	MMBtu/Ton
LOCATION	% US Production	% Supply for Destination	LOCATION [1]	% US Pro- duction	Normalized % Production	% Traveling this Route						
1. SAND [2]												
Amador & Contra Costa Counties, CA		100.0	San Francisco, CA	9.2	12.7	12.7	25 [3]	3	Truck	2500	0.01	
Clark Co., NV		100.0	Los Angeles, CA	9.2	12.7	12.7	225	29	Truck	2500	0.07	
Cumberland Co., NJ		100.0	Southern NJ	9.7	13.4	13.4	10 [3]	1	Truck	2500	0.00	
Cumberland Co., NJ		100.0	Northwest PA	9.7	13.4	13.4	250	34	Truck	2500	0.08	
Northern IL		100.0	Northern IL	8.6	11.9	11.9	100	12	Truck	2500	0.03	
Oklahoma		100.0	Oklahoma	6.5	9.0	9.0	100	9	Truck	2500	0.02	
Northern IL		100.0	Eastcentral IN	5.4	7.5	7.5	250	19	Truck	2500	0.05	
North Carolina		100.0	North Carolina	4.3	6.0	6.0	100	6	Truck	2500	0.01	
Bullock Co., AL		100.0	Florida	3.2	4.4	4.4	400	18	Rail	750	0.01	
Bullock Co., AL		100.0	Georgia	3.2	4.4	4.4	125	6	Truck	2500	0.01	
Cumberland Co., NJ		100.0	Central New York	3.2	4.4	4.4	225	10	Truck	2500	0.02	
TOTAL MMBtu/TON											0.16	
2. FELDSPAR [4]												
Southern Los Angeles		100.0	San Francisco, CA	9.2	12.7	12.7	400	51	Rail	750	0.04	
Southern Los Angeles		100.0	Los Angeles, CA	9.2	12.7	12.7	20	3	Truck	2500	0.01	
Cent/west NC	72.0	100.0	Southern NJ	9.7	13.4	13.4	550	74	Rail	750	0.06	
Cent/west NC	72.0	100.0	Northwest PA	9.7	13.4	13.4	450	60	Rail	750	0.05	
Cent/west NC	72.0	100.0	Northern IL	8.6	11.9	11.9	600	71	Rail	750	0.05	
Cent/west NC	72.0	100.0	Oklahoma	6.5	9.0	9.0	850	77	Rail	750	0.06	
Cent/west NC	72.0	100.0	Eastcentral IN	5.4	7.5	7.5	400	30	Rail	750	0.02	
Cent/west NC	72.0	100.0	North Carolina	4.3	6.0	6.0	100	6	Rail	750	0.004	
Cent/west NC	72.0	100.0	Florida	3.2	4.4	4.4	550	24	Rail	750	0.02	
Cent/west NC	72.0	100.0	Georgia	3.2	4.4	4.4	200	9	Rail	750	0.01	
Cent/west NC	72.0	100.0	Central New York	3.2	4.4	4.4	600	27	Rail	750	0.02	
TOTAL MMBtu/TON											0.11	

TABLE III-B.6 (CONTINUED)
TRANSPORT OF RAW MATERIALS FOR VIRGIN MOLTEN GLASS PRODUCTION

ORIGIN			FINAL DESTINATION			% Traveling this Route	Approximate Distance (mi.)	Weighted Miles	Mode	Btu/ Ton-Mile [8]	MMBtu/Ton
LOCATION	% US Production	% Supply for Destination	LOCATION [1]	% US Pro- duction	Normalized % Production						
3. NATURAL SODA ASH [5]											
Trona, CA	12.4	100.0	San Francisco, CA	9.2	12.7	12.7	280	36	Rail	750	0.03
Trona, CA	12.4	100.0	Los Angeles, CA	9.2	12.7	12.7	140	18	Rail	750	0.01
Southwest WY	87.6	100.0	Southern NJ	9.7	13.4	13.4	1825	245	Rail	750	0.18
Southwest WY	87.6	100.0	Northwest PA	9.7	13.4	13.4	1600	215	Rail	750	0.16
Southwest WY	87.6	100.0	Northern IL	8.6	11.9	11.9	1100	131	Rail	750	0.10
Southwest WY	87.6	100.0	Oklahoma	6.5	9.0	9.0	850	77	Rail	750	0.06
Southwest WY	87.6	100.0	Eastcentral IN	5.4	7.5	7.5	1300	97	Rail	750	0.07
Southwest WY	87.6	100.0	North Carolina	4.3	6.0	6.0	1750	104	Rail	750	0.08
Southwest WY	87.6	100.0	Florida	3.2	4.4	4.4	1850	82	Rail	750	0.06
Southwest WY	87.6	100.0	Georgia	3.2	4.4	4.4	1550	69	Rail	750	0.05
Southwest WY	87.6	100.0	Central New York	3.2	4.4	4.4	1900	84	Rail	750	0.06
TOTAL MMBtu/TON											0.36
4. LIMESTONE [6]											
California		100.0	San Francisco, CA	9.2	12.7	12.7	100	13	Rail	750	0.01
California		100.0	Los Angeles, CA	9.2	12.7	12.7	100	13	Rail	750	0.01
New Jersey		100.0	Southern NJ	9.7	13.4	13.4	100	13	Rail	750	0.01
Pennsylvania		100.0	Northwest PA	9.7	13.4	13.4	100	13	Rail	750	0.01
Illinois		100.0	Northern IL	8.6	11.9	11.9	100	12	Rail	750	0.01
Oklahoma		100.0	Oklahoma	6.5	9.0	9.0	100	9	Rail	750	0.01
Indiana		100.0	Eastcentral IN	5.4	7.5	7.5	100	7	Rail	750	0.01
North Carolina		100.0	North Carolina	4.3	6.0	6.0	100	6	Rail	750	0.004
Florida		100.0	Florida	3.2	4.4	4.4	100	4	Rail	750	0.003
Georgia		100.0	Georgia	3.2	4.4	4.4	100	4	Rail	750	0.003
New York		100.0	Central New York	3.2	4.4	4.4	100	4	Rail	750	0.003
TOTAL MMBtu/TON											0.07

TABLE III-B.6 (CONTINUED)
TRANSPORT OF RAW MATERIALS FOR VIRGIN MOLTEN GLASS PRODUCTION

Notes:

- [1] States and corresponding percentages for glass production, Source G-1, final destination location percentages based on 1987 "Number of establishments with 20 employees or more;" regions within states, Source G-2; CA split into two areas due to regional availability of sand.
- [2] Sand data, Source G-3; in 1988 imports accounted for 0.2% of "industrial sand and gravel consumption; used regions identified as glass sand producers."
- [3] Although sand is sourced from within glass producing state, because specific regions of sand and glass production are identified, we do not assume distance of 100 miles.
- [4] Feldspar data, Source G-4; in 1988 imports accounted for 1.0% of feldspar consumption.
- [5] Soda Ash data, Source G-5; in 1988 imports accounted for 1.9% of soda ash consumption.
- [7] Limestone data, Source G-6; in 1988 imports accounted for 0.3% of limestone consumption (based value of production/imports); crushed stone produced in all states but DE, therefore assumed acquired from within glass producing state.
- [8] Fuel efficiency, Source G-7.

TABLE III-B.7
TRANSPORT OF RAW MATERIALS FOR VIRGIN MOLTEN ALUMINUM PRODUCTION

STEP 1: Mining and refining of bauxite (bauxite to alumina)

ORIGIN			INTERMEDIATE DESTINATION								
LOCATION	% US Imports or Production	% Supply for Destination	LOCATION [1]	% US Con- sumption	Normalized %Production	% Traveling this Route	Approx. Dist. (miles)	Weighted Miles	Mode	Btu/ Ton-Mile [11]	MMBtu/Ton
1. BAUXITE [2]											
Guinea	31.7 [3]	50.4	Gulf Coast [5]	50.0	50.0	25.2	5640	1421	Ship	225	0.32
Jamaica	31.2 [3]	49.6	Gulf Coast			24.8	1500	372	Ship	225	0.08
Australia	50.0 [4]	100.0	Australia	50.0	50.0	50.0	25	13	Rail	750	0.01
TOTAL MMBtu/TON											0.41
3. CAUSTIC SODA [6]											
Gulf Coast		100.0	Gulf Coast	50.0	50.0	50.0	100	50	Rail	750	0.04
Australia		100.0	Australia	50.0	50.0	50.0	100	50	Rail	750	0.04
TOTAL MMBtu/TON											0.08

STEP 2: Smelting of alumina into aluminum

ORIGIN			FINAL DESTINATION								
LOCATION	% US Imports or Production	% Supply for Destination	LOCATION	% US Production	Normalized %Production	% Traveling this Route	Approx. Dist. (miles)	Weighted Miles	Mode	Btu/ Ton-Mile [a]	Btu/Ton
1. ALUMINA [7]											
Gulf Coast	50.0	100.0	Midwest	26.1	37.8	37.8	790	299	Rail	750	0.22
Gulf Coast	50.0	100.0	Texas	7.7	11.2	11.2	140	16	Rail	750	0.01
Australia	50.0	100.0	Pacific NW	35.3	51.0 [8]	51.0	9500	4848	Ship	225	1.09
TOTAL MMBtu/TON											1.33
2. CATHODES [9]											
Midwest		100.0	Midwest	26.1	37.8	37.8	750 [10]	284	Rail	750	0.21
Texas		100.0	Texas	7.7	11.2	11.2	750	84	Rail	750	0.06
Pacific NW		100.0	Pacific NW	35.3	51.0	51.0	750	383	Rail	750	0.29
TOTAL MMBtu/TON											0.56

TABLE III-B.7 (CONTINUED)
TRANSPORT OF RAW MATERIALS FOR VIRGIN MOLTEN ALUMINUM PRODUCTION

Notes:

- [1] In 1989 primary smelters consumed approximately 8 MMTons alumina; imported 9 MMTons bauxite for alumina production (equivalent to 3.9 MMTons alumina) and approximately 4.1 MMTons alumina for aluminum production. This means that 50% of U.S. aluminum was made from imported bauxite refined in the U.S., and 50% from imported alumina. Therefore, 50% of bauxite refining capacity is in U.S., and 50% in Australia (84% of 1989 alumina imports from Australia); Source A-1.
- [2] Bauxite data, Source A-1; in 1988 imports accounted for 98.7% of bauxite consumption.
- [3] Percent imports of bauxite to U.S.; normalized to 100%.
- [4] Because of alumina imports, 50% of bauxite ultimately used by U.S. aluminum industry is refined in Australia.
- [5] Approximately 90% of U.S. bauxite refining is in AL, AR, LA and TX, based on "Capacities of Domestic Alumina Plants," 1989.
- [6] Assumed caustic soda acquired from within aluminum producing state, and transported by rail.
- [7] Alumina data, Source A-1; final destination location percentages based on "Primary Annual Aluminum Production Capacity," 1989; Pacific NW includes WA & OR; Midwest includes IN, OH, KT, TN.
- [8] Source A-2; Imported alumina used primarily by Pacific NW smelters.
- [9] Source A-3; cathodes imported; anodes produced on-site.
- [10] Source A-3; average distance travelled within ALCOA system is 750 miles.
- [11] Fuel efficiency data, Source A-4.

TABLE III-B.8

TRANSPORT OF RAW MATERIALS FOR MOLTEN STEEL PRODUCTION (10% POST-CONSUMER CONTENT)

ORIGIN			FINAL DESTINATION			% Traveling this Route	Approximate Distance (mi.)	Weighted Miles	Mode	Btu/ Ton-Mile [9]	MMBtu/Ton
LOCATION	% US Production	% Supply for Destination	LOCATION	% US Production	Normalized % Production						
1. COAL [1,2]											
Kentucky	16.5	100.0	Indiana	21.5	28.4	28.4	350	99	Rail	750	0.07
West Virginia	15.4	100.0	Ohio	17.0	22.4	22.4	200	45	Rail	750	0.03
Pennsylvania [3]	7.2	50.0	Pennsylvania	12.2	16.1	8.1	100	8	Rail	750	0.01
West Virginia	15.4	50.0	Pennsylvania			8.1	200	16	Rail	750	0.01
Alabama [3,4]	2.7	50.0	Alabama	8.9	11.8	5.9	100	6	Rail	750	0.004
Kentucky	16.5	50.0	Alabama			5.9	300	18	Rail	750	0.01
Kentucky	16.5	100.0	Michigan	8.2	10.8	10.8	350	38	Rail	750	0.03
Illinois [3]	6.1	50.0	Illinois	7.9	10.4	5.2	100	5	Rail	750	0.004
Kentucky	16.5	50.0	Illinois			5.2	400	21	Rail	750	0.02
TOTAL MMBtu/TON											0.19
2. IRON ORE [5]											
Mesabi Range, MN	70.0	100.0	SW Lake Superior	-	66.9	66.9 [6]	65	43	Rail	750	0.03
SW Lake Superior	-	100.0	Indiana	21.5	28.4	28.4	850	241	Ship	225	0.05
SW Lake Superior	-	100.0	Lake Erie Ports, OH	17.0	22.4	22.4 [6]	900	202	Ship	225	0.05
Lake Erie Ports	-	100.0	Ohio	17.0	22.4	22.4	100	22	Rail	750	0.02
SW Lake Superior	-	100.0	Lake Erie Ports, PA	12.2	16.1	16.1 [6]	900	145	Ship	225	0.03
Lake Erie Ports	-	100.0	Pennsylvania	12.2	16.1	16.1	125	20	Rail	750	0.02
Venezuela	-	100.0	Mobile, Alabama	8.9	11.8	11.8 [6]	2700	319	Ship	225	0.07
Mobile, Alabama		100.0	Alabama	8.9	11.8	11.8	200	24	Rail	750	0.02
Upper Penn., MI	24.0	100.0	Marquette, MI	8.2	10.8	10.8 [6]	30	3	Rail	750	0.002
Marquette, MI	-	100.0	Michigan	8.2	10.8	10.8	500	54	Ship	225	0.01
Mesabi Range, MN	70.0	100.0	Illinois	7.9	10.4	10.4	600	63	Rail	750	0.05
TOTAL MMBtu/TON											0.35

TABLE III-B.8 (CONTINUED)
TRANSPORT OF RAW MATERIALS FOR MOLTEN STEEL PRODUCTION (10% POST-CONSUMER CONTENT)

ORIGIN			FINAL DESTINATION			% Traveling this Route	Approximate Distance (mi.)	Weighted Miles	Mode	Btu/ Ton-Mile [9]	MMBtu/Ton
LOCATION	% US Production	% Supply for Destination	LOCATION	% US Production	Normalized % Production						
3. LIMESTONE [7]											
Indiana		100.0	Indiana	21.5	30.3	30.3	100	30	Rail	750	0.02
Ohio		100.0	Ohio	17.0	23.9	23.9	100	24	Rail	750	0.02
Pennsylvania		100.0	Pennsylvania	12.2	16.1	16.1	100	16	Rail	750	0.01
Alabama		100.0	Alabama	8.9	11.8	11.8	100	12	Rail	750	0.01
Michigan		100.0	Michigan	8.2	10.8	10.8	100	11	Rail	750	0.01
Illinois		100.0	Illinois	7.9	10.4	10.4	100	10	Rail	750	0.01
										TOTAL MMBtu/TON	0.08
4. LIME [8]											
Indiana	20.8	100.0	Indiana	21.5	30.3	30.3	100	30	Rail	750	0.02
Ohio	11.9	100.0	Ohio	17.0	23.9	23.9	100	24	Rail	750	0.02
Pennsylvania	9.5	100.0	Pennsylvania	12.2	16.1	16.1	100	16	Rail	750	0.01
Alabama	8.4	100.0	Alabama	8.9	11.8	11.8	100	12	Rail	750	0.01
Michigan	4.1	100.0	Michigan	8.2	10.8	10.8	100	11	Rail	750	0.01
Illinois	20.8	100.0	Illinois	7.9	10.4	10.4	100	10	Rail	750	0.01
										TOTAL MMBtu/TON	0.08

Notes:

[1] In 1989, coal imports accounted for 0.3% of consumption; in 1989, coke imports accounted for 6.8% of consumption. (Source S-1)

[2] Coal data (origin), Source S-2; Steel production data (destination), Source S-3.

[3] According to comparison between "Coal Received at Coke Plants" and "Shipments of coal by District and Consumer Use, 1988," PA, AL and IL produce only about half of the coal consumed by their coke plants; it is assumed that the remaining 50% comes from the nearest coal producing state.

[4] Percentage of raw steel production for Alabama, 8.9%, is actually aggregate number reported for AL, TN, KY, MS, and AR.

[5] Iron Ore data, Source S-4; In 1989 imports accounted for 24.4% of iron ore consumption; although this is less than 30%, imports of iron ore to Alabama are included because imports are the known source for Alabama's steel industry.

[6] Although these are not final destinations, they are simply places where modes of transport change, and not intermediate processing areas.

[7] Limestone data, Source S-5; in 1988 imports accounted for 0.3% of limestone consumption (based value of production/imports); crushed stone produced in all states but DE, therefore assumed acquired from within steel producing state.

[8] Lime data, Source S-6; In 1988 imports accounted for 1.2% of lime consumption; percentage of lime production for IN and IL is aggregate for IL, IN, MO.

[9] Fuel efficiency, Source S-7.

TABLE III-B.9
TRANSPORT OF RAW MATERIALS FOR VIRGIN LUBRICATING OIL BASE STOCK

ORIGIN			FINAL DESTINATION [1,2]					Weighted Miles	Mode	Btu/ Ton-Mile [8]	MMBtu/Ton	
LOCATION	% US Imports or Production	% Supply for Destination	LOCATION	% US Production	Normalized % Production	% Traveling this Route	Approximate Distance (mi.)					
1 1. CRUDE OIL [3,4]												
1.a.	Gulf Coast		56.0	Gulf Coast	-	88.1 [5]	49.3	100	49	Pipeline	2085	0.10
	Middle East	30.4	17.1	Gulf Coast			15.0	16,000	2406	Ship	225	0.54
	Africa	22.0	12.4	Gulf Coast			10.9	7500	818	Ship	225	0.18
	South America	13.6	7.7	Gulf Coast			6.7	2,200	148	Ship	225	0.03
	Mexico	12.3	6.9	Gulf Coast			6.1	700	42	Ship	225	0.01
1.b.	Gulf Coast		100.0	Gulf Coast	56.2	66.6	66.6	100 [7]	67	Pipeline	2085	0.14
	California		50.0	California	10.1	11.9	6.0	100 [7]	6	Pipeline	2085	0.01
	Alaska		50.0	California			6.0	1,400	84	Ship	225	0.02
	Gulf Coast		100.0	Midwest [6]	9.6	11.4	11.4	775	88	Pipeline	2085	0.18
	Gulf Coast		100.0	Pennsylvania	8.5	10.1	10.1	1075	108	Pipeline	2085	0.23
TOTAL MMBtu/TON											1.45	

Notes

[1] "Final Desinations" are lube oil producers; lube oil producers may be integrated with refinery (therefore equivalent of final destination) or may be separate from refinery. Because all lube producing states are also significant refining areas, it is assumed that refining of crude oil takes place in lube producing state; additional assumption that when oil is obtained from out of state, transport of feedstock material from refinery to lube producer is negligible compared to transport of raw material to the lube producing state.

[2] Location of lube oil producers, Source L-1.

[3] Source L-2; in 1989 imports accounted for approximately 44% of petroleum demand.

[4] Because Gulf Coast is gate for crude oil imports into United States, part "a" calculates transportation of oil to Gulf Coast, apportioned 56% domestic and 44% imported (import percentages normalized to account for 100% of imports, and multiplied by 44%); part "b" is transport of crude to lube producing states.

[5] Sum of normalized lube oil production percentages of areas that acquire crude oil from Gulf Coast (GC, Midwest, PA).

[6] Midwest includes IL, IN, OH, KY.

[7] Because extraction, refining and feedstock production occur within the state, transportation between raw material or feedstock producer and lube producer is 100 miles ("in-state rule").

[8] Fuel efficiency for ship, Source L-3; fuel efficiency for pipeline calculated from Source L-4.

TABLE III-B.10 RECYCLED MATERIALS TRANSPORTATION ENERGY

Recyclable Material	Destination Facility Types	Approximate Number of Facilities	Estimated Distance (Miles)	% Mode	Btu/ Ton-Mile [1]	Total MMBtu/ Ton
Corrugated boxes/kraft paper	Recycled linerboard mills	12	500	100% Truck	2500	1.25
Newspapers	Recycled newsprint mills	5	750	70% Truck 30% Rail	2500 750	1.48
Office/computer paper	Recycled office paper mills	20	250	100% Truck	2500	0.63
Magazines/glossy paper/ books/telephone books	Recycled coated folding boxboard mills	30	250	100% Truck	2500	0.63
HDPE containers	Post consumer recyclers	16	250	100% Truck	2500	0.63
LDPE films & bags	Post consumer recyclers	9	500	100% Truck	2500	1.25
PET containers	Post consumer recyclers	6	500	100% Truck	2500	1.25
Glass containers	Glass container factories	80	250	100% Truck	2500	0.63
Aluminum cans, foil	Aluminum processors/ primary mills	25	250	100% Truck	2500	0.63
Steel/tin containers and ferrous scrap	Mini-mills	60	250	100% Truck	2500	0.63

TABLE III-B.10 (CONTINUED) RECYCLED MATERIALS TRANSPORTATION ENERGY

Recyclable Material	Destination Facility Types	Approximate Number of Facilities	Estimated Distance (Miles)	% Mode	Btu/ Ton-Mile [1]	Total MMBtu/ Ton
Brick/concrete						
Used lubricating oil	Rerefinerles	4	750	80% Truck 20% Rail	2500 750	1.61

Notes:

[1] Btu/Ton-mile source: The Aluminum Association, Inc. "Energy Content in Aluminum Cans: Historical Performance and Future Potential," Report No. 7, June 1984.

APPENDIX III-B TRANSPORTATION ENERGY SOURCES

TABLES III-B.1-4:

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APPENDIX III-C
BIBLIOGRAPHY ON ENERGY USE IN SELECTED
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APPENDIX III-C

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APPENDIX V-A
MANUFACTURING SYSTEM ENERGY IMPACT TABLES,
SCENARIOS A, B, C, AND D

TABLE V-A.1. Manufacturing System Energy Impacts - Scenario A

Recyclable	Recyclables Diverted (Tons/yr)	Manufacturing Energy Coefficient (MMBtu/ton) [2]	Total Energy Savings (MMBtu/yr)
Paper/Paperboard:			
Corrugated Boxes/Kraft Paper	693,295	2.62	1.82E+06
Newspapers	351,358	9.42	3.31E+06
Office/Computer Paper	313,193	9.41	2.95E+06
Mixed Paper	396,873	3.07	1.22E+06
Plastics:			
HDPE Containers: clear and colored	78,251	40.66	3.18E+06
LDPE films and bags	32,539	48.66	1.58E+06
PET containers: clear and green	32,750	32.80	1.07E+06
Glass:			
Glass Containers: clear, green, and brown	72,276	1.91	1.38E+05
Metal:			
Aluminum: cans, foil, misc.	46,245	128.75	5.95E+06
Steel/ Tin Food Containers and Ferrous Scrap	178,559	19.33	8.94E+05
Miscellaneous:			
Brick/Concrete	555,163	0.05	2.78E+04
Waste Lubricating Oil		1.91	0.00E+00

2,750,502 Tons Recycled [1]

Total Energy Savings from Recycling 2.21E+07

[1] Does not include mixed glass, mixed plastics, bulk recycling, textiles, non-bulk ceramics or batteries.

[2] From Table 5.1.

TABLE V-A.2. Manufacturing System Energy Impacts - Scenario B

Recyclable	Recyclables Diverted (Tons/yr)	Manufacturing Energy Coefficient (MMBtu/ton) [2]	Total Energy Savings (MMBtu/yr)
Paper/Paperboard:			
Corrugated Boxes/Kraft Paper	693,295	2.62	1.82E+06
Newspapers	369,888	9.42	3.48E+06
Office/Computer Paper	316,267	9.41	2.98E+06
Mixed Paper	401,727	3.07	1.23E+06
Plastics:			
HDPE Containers: clear and colored	79,649	40.66	3.24E+06
LDPE films and bags	32,539	48.66	1.58E+06
PET containers: clear and green	33,199	32.80	1.09E+06
Glass:			
Glass Containers: clear, green, and brown	74,550	1.91	1.42E+05
Metal:			
Aluminum: cans, foil, misc.	45,548	128.75	5.86E+06
Steel/ Tin Food Containers and Ferrous Scrap	186,190	19.33	8.80E+05
Miscellaneous:			
Brick/Concrete	555,163	0.05	2.78E+04
Waste Lubricating Oil	0	1.91	0.00E+00
2,788,015 Tons Recycled [1]			
Total Energy Savings from Recycling			2.23E+07

[1] Does not include mixed glass, mixed plastics, bulk recycling, textiles, non-bulk ceramics or batteries.

[2] From Table 5.1.

TABLE V-A.3. Manufacturing System Energy Impacts - Scenario C

Recyclable	Recyclables Diverted (Tons/yr)	Manufacturing Energy Coefficient (MMBtu/ton) [2]	Total Energy Savings (MMBtu/yr)
Paper/Paperboard:			
Corrugated Boxes/Kraft Paper	741,576	2.62	1.94E+06
Newspapers	334,440	9.42	3.15E+06
Office/Computer Paper	297,886	9.41	2.80E+06
Mixed Paper	372,880	3.07	1.14E+06
Plastics:			
HDPE Containers: clear and colored	82,410	40.66	3.35E+06
LDPE films and bags	31,265	48.66	1.52E+06
PET containers: clear and green	34,124	32.80	1.12E+06
Glass:			
Glass Containers: clear, green, and brown	77,996	1.91	1.49E+05
Metal:			
Aluminum: cans, foil, misc.	45,341	128.75	5.84E+06
Steel/ Tin Food Containers and Ferrous Scrap	203,505	19.33	8.76E+05
Miscellaneous:			
Brick/Concrete	555,163	0.05	2.78E+04
Waste Lubricating Oil	0	1.91	0.00E+00
<u>2,776,586 Tons Recycled [1]</u>			
Total Energy Savings from Recycling			<u>2.19E+07</u>

[1] Does not include mixed glass, mixed plastics, bulk recycling, textiles, non-bulk ceramics or batteries.

[2] From Table 5.1.

TABLE V-A.4. Manufacturing System Energy Impacts - Scenario D

Recyclable	Recyclables Diverted (Tons/yr)	Manufacturing Energy Coefficient (MMBtu/ton) [2]	Total Energy Savings (MMBtu/yr)
Paper/Paperboard:			
Corrugated Boxes/Kraft Paper	517,460	2.62	1.36E+0
Newspapers	140,038	9.42	1.32E+0
Office/Computer Paper	233,415	9.41	2.20E+0
Mixed Paper	204,338	3.07	6.27E+0
Plastics:			
HDPE Containers: clear and colored	31,191	40.66	1.27E+0
LDPE films and bags	1,717	48.66	8.35E+0
PET containers: clear and green	12,923	32.80	4.24E+0
Glass:			
Glass Containers: clear, green, and brown	38,276	1.91	7.31E+0
Metal:			
Aluminum: cans, foil, misc.	9,712	128.75	1.25E+0
Steel/ Tin Food Containers and Ferrous Scrap	157,753	19.33	1.88E+0
Miscellaneous:			
Brick/Concrete	555,163	0.05	2.78E+0
Waste Lubricating Oil	0	1.91	0.00E+0
1,901,986 Tons Recycled [1]			
Total Energy Savings from Recycling			8.81E+0

[1] Does not include mixed glass, mixed plastics, bulk recycling, textiles, non-bulk ceramics or batteries.

[2] From Table 5.1.

APPENDIX V-B

SPATIAL ANALYSIS TABLES, REGIONS 1, 2, 3, AND 4

**FOR THE NEW YORK CITY CASE STUDY, SOLID WASTE MANAGEMENT
SCENARIO B**

TABLE V-B.1 SPATIAL ANALYSIS, RECYCLED MANUFACTURING-REGION 1

Recyclable Material	Total Mat. Diverted Fm Waste Strm (tons/yr)	Processes	Process Output	Waste Mater. Util. in Region (tons/yr)	Tons Recyclable Material/Ton Process Output	Production Capacity in Region (tons product/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption			
									Oil (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
OCC	693,295	pulping and boardmaking	linerboard	0	1.15	0	0.00E+00	0.00E+00				
ONP	369,888	pulping, deinking and papermaking	newsprint	60	1.17	51	3.37E+04	3.19E+05				
Office/Computer Paper	316,267	pulping, deinking and papermaking	office paper	0	1.14	0	0.00E+00	0.00E+00				
Mixed Paper (Inc. mag./glossy)	401,727	pulping and boardmaking	folding boxboard	40	1.03	39	2.58E+04	4.23E+05				
HDPE containers	79,649	grinding, cleaning and extruding	HDPE pellets	4,700	1.00	4,700	4.70E+06					
LDPE films and bags	32,539	grinding, cleaning and extruding	LDPE pellets	0	1.00	0	0.00E+00					
PET containers	33,199	grinding, cleaning and extruding	PET pellets	4,700	1.00	4,700	4.70E+06					
Glass	74,550	crushing, cleaning and melting	molten glass	0	1.00	0	0.00E+00					
Aluminum (cans and foil)	45,548	shredding, deaerating and melting	molten alum.	0	1.11	0	0.00E+00					
Steel (cans and scrap)	186,190	shredding and melting	molten steel	0	0.99	0	0.00E+00					
Total Process Energy							9.46E+06	7.42E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total Process MMBtu							9.93E+04	1.04E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TABLE V-B.2 SPATIAL ANALYSIS, VIRGIN MANUFACTURING-REGION 1

Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Virgin Product	Processes	Process Output	Potential Max. Output Displaced (tons/yr)	Change In Process Output In Region (tons/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption			
									Oil [1] (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
OCC	693,295	Linerboard	wood harvesting through boardmaking	Linerboard	602,865	0						
ONP	369,888	Newsprint	wood harvesting through TMP prod.	TM pulp (air dry)	262,670	0						
			wood harvesting through bleached kraft pulp prod.	bl.kraft pulp (air dry)	13,825	0						
			forming and drying	newsprint	317,044	0						
Office/Computer Paper	316,267	Printing/Writing Paper	wood harvesting through papermaking	printing/writing paper	277,063	0						
			chlorine production	chlorine	9,667	0						
			caustic production	caustic	15,921	0						
Mixed Paper (inc. mag./glossy)	401,727	Folding boxboard	wood harvesting through boardmaking	folding boxboard	391,081	0						
HDPE containers	79,649	HDPE Pellets	petroleum extraction	crude oil	278,294	0						
			natural gas extraction	natural gas (cf)	2,533,503,877	0						
			oil and gas refining	HDPE pellets	79,649	0						
			through resin production									
LDPE films and bags	32,539	LDPE Pellets	petroleum extraction	crude oil	117,035	0						
			natural gas extraction	natural gas (cf)	1,065,453,683	0						
			oil and gas refining	LDPE pellets	32,539	0						
			through resin production									
PET containers	33,199	PET Pellets	petroleum extraction	crude oil	136,518	0						
			natural gas extraction	natural gas (cf)	264,519,066	0						
			oil and gas refining	PET pellets	33,199	0						
			through resin production									

TABLE V-B.2 SPATIAL ANALYSIS, VIRGIN MANUFACTURING-REGION 1 (cont.)

Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Virgin Product	Processes	Process Output	Potential Max. Output Displaced (tons/yr)	Change in Process Output in Region (tons/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption			
									Oil (1) (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
Glass Containers	74,550	Molten Glass	sand mining	sand	39,139	0						
			limestone mining/proc.	limestone	11,043	0						
			feldspar mining/process.	feldspar	3,355	0						
			soda ash mining/proc.	soda ash	12,301	0						
			cullet crushing through melting	molten glass	74,550	0						
Aluminum cans & foil	45,548	Molten Aluminum	bauxite mining/process.	bauxite	183,873	0						
			caustic soda production	caustic soda	5,037	0						
			Bayer process	alumina	79,945	0						
			Hall-Heroult process	aluminum	40,997	0						
Steel cans & ferrous scrap	186,190	Molten Steel	iron ore mining	raw feed ore	39,448	0						
			iron ore mining/process.	iron ore pellets	240,983	0						
			limestone mining/proc.	limestone	72,738	0						
			lime processing	lime	10,688	0						
			coal mining/process.	coal	143,711	0						
			coke, sinter and pellet production through molten steel (BOF)	steel	187,503	0						
Brick/concrete	555,163	Aggregate	gravel mining/processing	aggregate	555,163	0						
Total Process Energy							0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total Process MMBtu							0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TABLE V-B.3 SPATIAL ANALYSIS, RECYCLED MANUFACTURING-REGION 2

Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Processes	Process Output	Waste Mater. Util. in Region (tons/yr)	Tons Recyclable Material/Ton Process Output	Production Capacity in Region (tons product/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption				
									Oil (gal/yr)	natural Ga (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)	
OCC	693,295	pulping and boardmaking	linerboard	372,000	1.15	323,478	2.02E+08	3.28E+09					
ONP	369,828	pulping, deinking and papermaking	newsprint	172,000	1.17	147,427	9.65E+07	9.14E+08					
Office/Computer Paper	316,267	pulping, deinking and papermaking	office paper	43,800	1.14	38,371	2.62E+07	2.48E+08					
Mixed Paper (Inc. mag./glossy)	401,687	pulping and boardmaking	folding boxboard	150,750	1.03	146,755	9.65E+07	1.59E+09					
HDPE containers	74,949	grinding, cleaning and extruding	HDPE pellets	37,474	1.00	37,474	3.75E+07						
LDPE films and bags	32,539	grinding, cleaning and extruding	LDPE pellets	16,269	1.00	16,269	2.44E+07						
PET containers	28,499	grinding, cleaning and extruding	PET pellets	14,249	1.00	14,249	1.42E+07						
Glass	74,550	crushing, cleaning and melting	molten glass	74,550	1.00	74,550	5.31E+06			2.71E+08			
Aluminum (cans and foil)	45,548	shredding, deaer- ing and melting	molten alum.	0	1.11	0	0.00E+00						
Steel (cans and scrap)	186,190	shredding and melting	molten steel	93,095	0.99	93,751	3.70E+07		8.91E+02	1.74E+07	3.17E+02	1.14E+02	
Total Process Energy							5.39E+08	6.04E+09	8.91E+02	2.89E+08	3.17E+02	1.14E+02	
Total Process MMBtu							5.66E+08	8.45E+08	1.33E+02	2.97E+05	7.93E+03	1.14E+02	1.44E+07

TABLE V-B.4 SPATIAL ANALYSIS, VIRGIN MANUFACTURING-REGION 2

Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Virgin Product	Processes	Process Output	Potential Max. Output Displaced (tons/yr)	Change in Process Output in Region (tons/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption			
									Oil [1] (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
OCC	693,295	Linerboard	wood harvesting through boardmaking	linerboard	602,865	0						
ONP	420,371	Newsprint	wood harvesting through TMP prod.	TM pulp (air dry)	262,670	0						
			wood harvesting through bleached kraft pulp prod.	bl. kraft pulp (air dry)	13,825	0						
			forming and drying	newsprint	317,044	0						
Office/Computer Paper	316,267	Printing/Writing Paper	wood harvesting through papermaking	printing/writing paper	277,063	50,000	1.92E+07	6.54E+08	6.56E+05			
			chlorine production	chlorine	9,667	0						
			caustic production	caustic	15,921	0						
Mixed Paper (Inc. mag./glossy)	401,727	Folding boxboard	wood harvesting through boardmaking	folding boxboard	391,081	0						
HDPE containers	79,849	HDPE Pellets	petroleum extraction	crude oil	278,294	0						
			natural gas extraction	natural gas (cf)	2,533,503,877	0						
			oil and gas refining through resin production	HDPE pellets	79,849	0						
LDPE films and bags	32,539	LDPE Pellets	petroleum extraction	crude oil	117,035	0						
			natural gas extraction	natural gas (cf)	1,065,453,683	0						
			oil and gas refining through resin production	LDPE pellets	32,539	0						
PET containers	33,199	PET Pellets	petroleum extraction	crude oil	136,518	0						
			natural gas extraction	natural gas (cf)	264,519,066	0						
			oil and gas refining through resin production	PET pellets	33,199	0						

TABLE V-B.4 SPATIAL ANALYSIS, VIRGIN MANUFACTURING-REGION 2 (cont.)

Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Virgin Product	Processes	Process Output	Potential Max. Output Displaced (tons/yr)	Change in Process Output In Region (tons/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption			
									Oil [1] (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
Glass Containers	74,550	Molten Glass	sand mining	sand	39,139	39,139						1.84E+04
			limestone mining/proc.	limestone	11,043	11,043	4.03E+04		1.56E+03	1.35E+05		1.99E+02
			feldspar mining/process.	feldspar	3,355	0						
			soda ash mining/proc.	soda ash	12,301	0						
			cullet crushing through melting	molten glass	74,550	74,550	3.83E+06			3.43E+08		
Aluminum cans & foil	45,548	Molten Aluminum	bauxite mining/process.	bauxite	183,873	0						
			caustic soda production	caustic soda	5,037	0						
			Bayer process	alumina	79,945	0						
			Hall-Heroult process	aluminum	40,997	0						
Steel cans & ferrous scrap	186,190	Molten Steel	iron ore mining	raw feed ore	39,448	0						
			iron ore mining/process.	iron ore pellets	240,983	0						
			limestone mining/proc.	limestone	72,738	0						
			lime processing	lime	10,688	0						
			coal mining/process.	coal	143,711	0						
			coke, sinter and pellet production through molten steel (BOF)	steel	187,503	0						
Brick/concrete	555,163	Aggregate	gravel mining/processing	aggregate	555,163	555,163	2.64E+06					
Total Process Energy							2.57E+07	6.54E+08	6.58E+05	3.44E+08	0.00E+00	1.86E+04
Total Process MMBtu							2.70E+05	9.16E+05	9.85E+04	3.54E+05	0.00E+00	1.86E+04
												1.66E+06

TABLE V-B.5 SPATIAL ANALYSIS, RECYCLED MANUFACTURING-REGION 3

TABLE V-B.5 SPATIAL ANALYSIS, RECYCLED MANUFACTURING REGION 3												
Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Processes	Process Output	Waste Mater. Util. in Region (tons/yr)	Tons Recyclable Material/Ton Process Output	Production Capacity in Region (tons product/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption			
									Oil (gal/yr)	atural Ga (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
OCC	321,295	pulping and boardmaking	linerboard	0	1.15	0	0.00E+00					
ONP	197,828	pulping, deinking and papermaking	newsprint	0	1.17	0	0.00E+00					
Office/Computer Paper	272,467	pulping, deinking and papermaking	office paper	136,234	1.14	119,348	8.14E+07	7.70E+08				
Mixed Paper (inc. mag./glossy)	250,937	pulping and boardmaking	folding boxboard	125,469	1.03	122,143	8.03E+07	1.33E+09				
HDPE containers	37,475	grinding, cleaning and extruding	HDPE pellets	37,475	1.00	37,475	3.75E+07					
LDPE films and bags	16,270	grinding, cleaning and extruding	LDPE pellets	16,270	1.00	16,270	2.44E+07					
PET containers	14,250	grinding, cleaning and extruding	PET pellets	14,250	1.00	14,250	1.43E+07					
Glass	0	crushing, cleaning and melting	molten glass	0	1.00	0	0.00E+00					
Aluminum (cans and foil)	45,548	shredding, delaq- ering and melting	molten alum.	45,548	1.11	40,997	7.03E+06			2.59E+08		
Steel (cans and scrap)	93,095	shredding and melting	molten steel	93,095	0.99	93,761	3.70E+07		8.91E+02	1.74E+07	3.17E+02 1.14E+02	
Total Process Energy							2.82E+08	2.10E+09	8.91E+02	2.77E+08	3.17E+02 1.14E+02	
Total Process MMBtu							2.96E+06	2.93E+06	1.33E+02	2.85E+05	7.93E+03 1.14E+02 6.19E+06	

TABLE V-B.6 SPATIAL ANALYSIS, VIRGIN MANUFACTURING-REGION 3

Recyclable Material	Mat. Diverted Fr Waste Strm (tons/yr)	Virgin Product	Processes	Process Output	Potential Max. Output Displaced (tons/yr)	Change In Process Output in Region (tons/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption			
									Oil [1] (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
OCC	693,295	Linerboard	wood harvesting through boardmaking	linerboard	602,865	602,865	1.43E+08	8.62E+09	7.08E+06			
ONP	420,371	Newsprint	wood harvesting through TMP prod.	TM pulp (air dry)	262,670	131,335	2.45E+08	1.29E+08	1.97E+05			
			wood harvesting through bleached kraft pulp prod.	bl.kraft pulp (air dry)	13,825	6,912	1.56E+08	6.67E+07	9.63E+04			
			forming and drying	newsprint	317,044	158,522	2.77E+07	6.34E+08				
Office/Computer Paper	316,267	Printing/Writing Paper	wood harvesting through papermaking	printing/writing paper	277,063	277,063	1.06E+08	3.62E+09	3.64E+06			
			chlorine production	chlorine	9,667	9,667	1.73E+07	9.00E+06				
			caustic production	caustic	15,921	15,921	2.34E+07	1.43E+08				
Mixed Paper (Inc. mag./glossy)	401,727	Folding boxboard	wood harvesting through boardmaking	folding boxboard	391,081	391,081	8.27E+07	5.87E+09	4.59E+06			
HDPE containers	79,649	HDPE Pellets	petroleum extraction	crude oil	278,294	139,147	3.58E+05		5.19E+05			2.27E+01
			natural gas extraction	natural gas (cf)	2,533,503,877	2,533,503,877			1.26E+06			
			oil and gas refining	HDPE pellets	79,649	79,649	2.38E+07	4.57E+07		1.83E+09		2.49E+06
			through resin production									
LDPE films and bags	32,539	LDPE Pellets	petroleum extraction	crude oil	117,035	58,518	1.51E+05		2.18E+05			9.54E+00
			natural gas extraction	natural gas (cf)	1,065,453,683	1,065,453,683			5.28E+05			
			oil and gas refining	LDPE pellets	32,539	32,539	4.18E+07	6.80E+07		7.68E+08		1.05E+06
			through resin production									
PET containers	33,199	PET Pellets	petroleum extraction	crude oil	136,518	68,259	1.76E+05		2.55E+05			1.11E+01
			natural gas extraction	natural gas (cf)	264,519,066	264,519,066			1.31E+05			
			oil and gas refining	PET pellets	33,199	33,199	1.55E+07	3.02E+08		1.91E+08		8.01E+05
			through resin production									

TABLE V-B.6 SPATIAL ANALYSIS, VIRGIN MANUFACTURING-REGION 3 (cont.)

								Process Fuel Consumption					
Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Virgin Product	Processes	Process Output	Potential Max. Output Displaced (tons/yr)	Change in Process Output in Region (tons/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Oil [1] (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)	
Glass Containers	0	Molten Glass	sand mining	sand	0	0	1.27E+05		2.09E+04			8.26E+04	
			limestone mining/proc.	limestone	0	0							
			feldspar mining/process.	feldspar	3,355	3,355							
			soda ash mining/proc.	soda ash	12,301	12,301							
			cullet crushing through melting	molten glass	0	0							
Aluminum cans & foil	45,548	Molten Aluminum	bauxite mining/process.	bauxite	183,873	0	5.18E+06	3.17E+07	3.47E+05	5.45E+08	2.63E+03	5.41E+02	
			caustic soda production	caustic soda	5,037	3,526							
			Bayer process	alumina	79,945	55,961							
			Hall-Heroult process	aluminum	40,997	40,997							
Steel cans & ferrous scrap	186,190	Molten Steel	iron ore mining	raw feed ore	39,448	39,448	9.86E+05	2.38E+08	6.18E+03	5.64E+03	1.00E+03	1.31E+03	
			iron ore mining/process.	iron ore pellets	240,983	240,983	2.67E+07		5.10E+05	6.63E+07			
			limestone mining/proc.	limestone	72,738	72,738	2.65E+05		1.02E+04	8.91E+05			
			lime processing	lime	10,688	10,688	2.99E+05			2.51E+07			
			coal mining/process.	coal	143,711	143,711							
			coke, sinter and pellet production through molten steel (BOF)	steel	187,503	187,503	1.84E+07		5.65E+05	2.63E+08			
Brick/concrete	0	Aggregate	gravel mining/processing	aggregate	0	0							
Total Process Energy							1.23E+09	1.98E+10	2.00E+07	3.82E+09	1.11E+05	5.16E+06	
Total Process MMBtu							1.29E+07	2.77E+07	3.00E+06	3.94E+06	2.78E+06	5.16E+06	5.55E+07

TABLE V-B.7 SPATIAL ANALYSIS, RECYCLED MANUFACTURING-REGION 4

Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Processes	Process Output	Waste Mater. Util. in Region (tons/yr)	Tons Recyclable Material/Ton Process Output	Production Capacity in Region (tons product/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption			
									Oil (gal/yr)	atural Ga (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
OCC	321,295	pulping and boardmaking	linerboard	321,295	1.15	279,387	1.74E+08	2.83E+09				
ONP	197,828	pulping, deinking and papermaking	newsprint	197,828	1.17	169,568	1.11E+08	1.05E+09				
Office/Computer Paper	138,234	pulping, deinking and papermaking	office paper	138,234	1.14	119,348	8.14E+07	7.70E+08				
Mixed Paper (Inc. mag./glossy)	125,469	pulping and boardmaking	folding boxboard	125,469	1.03	122,143	8.03E+07	1.33E+09				
HDPE containers	0	grinding, cleaning and extruding	HDPE pellets	0	1.00	0						
LDPE films and bags	0	grinding, cleaning and extruding	LDPE pellets	0	1.00	0						
PET containers	0	grinding, cleaning and extruding	PET pellets	0	1.00	0						
Glass	0	crushing, cleaning and melting	molten glass	0	1.00	0						
Aluminum (cans and foil)	0	shredding, deinking and melting	molten alum.	0	1.11	0						
Steel (cans and scrap)	0	shredding and melting	molten steel	0	0.99	0						
Total Process Energy							4.47E+08	5.98E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total Process MMBtu							4.69E+06	8.37E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
												1.31E+07

TABLE V-B.8 SPATIAL ANALYSIS, VIRGIN MANUFACTURING-REGION 4

Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Virgin Product Lumberboard	Processes wood harvesting through boardmaking	Process Output linerboard	Potential Max. Change in Process Output Displaced (tons/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Oil [1] (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)
ONP	210,185	Newsprint	wood harvesting through TMP prod. wood harvesting through bleached kraft pulp prod. forming and drying newsprint	TM pulp (air dry) 131,335	6,912	158,522	158,522	2,77E+07	6,34E+08	9,63E+04	1,97E+05
Office/Computer Paper	0	Printing/Writing Paper	wood harvesting through papermaking chlorine production caustic production	printing/writing paper 0	0	0	0				
Mixed Paper (inc. meg./grossy)	0	Folding boardboard	wood harvesting through boardmaking	folding boardboard 0	0	0	0				
HDPE containers	0	HDPE Pellets	petroleum extraction natural gas extraction oil and gas refining through resin production	crude oil 139,147	139,147	139,147	139,147	3,58E+05	5,19E+05	0,00E+00	2,27E+01
LDPE films and bags	0	LDPE Pellets	petroleum extraction natural gas extraction oil and gas refining through resin production	crude oil 58,518	58,518	58,518	58,518	1,51E+05	2,18E+05	0,00E+00	9,54E+00
PET containers	0	PET Pellets	petroleum extraction oil and gas refining through resin production	crude oil 68,258	68,258	68,258	68,258	1,76E+05	2,55E+05	0,00E+00	1,11E+01

TABLE V-B.8 SPATIAL ANALYSIS, VIRGIN MANUFACTURING-REGION 4 (cont.)

Recyclable Material	Mat. Diverted Fm Waste Strm (tons/yr)	Virgin Product	Processes	Process Output	Potential Max. Output Displaced (tons/yr)	Change In Process Output In Region (tons/yr)	Electricity (kWh/yr)	Steam (pounds/yr)	Process Fuel Consumption				
									Oil [1] (gal/yr)	Natural Gas (cu ft/yr)	Coal (tons/yr)	Other (MMBtu/yr)	
Glass Containers	0	Molten Glass	sand mining	sand	0	0							
			limestone mining/proc.	limestone	0	0							
			feldspar mining/process.	feldspar	0	0							
			soda ash mining/proc.	soda ash	0	0							
			cullet crushing through melting	molten glass	0	0							
Aluminum cans & foil	0	Molten Aluminum	bauxite mining/process.	bauxite	183,873	183,873	1.99E+06	1.36E+07	7.60E+04	8.28E+06		9.48E+02	
			caustic soda production	caustic soda	1,511	1,511	2.22E+06						
			Bayer process	alumina	23,983	23,983	4.53E+06		1.49E+05	2.34E+08	1.13E+03	2.32E+02	
			Hell-Heroult process	aluminum	0	0							
Steel cans & ferrous scrap	0	Molten Steel	Iron ore mining	raw feed ore	0	0							
			iron ore mining/process.	iron ore pellets	0	0							
			limestone mining/proc.	limestone	0	0							
			lime processing	lime	0	0							
			coal mining/process.	coal	0	0							
			coke, sinter and pellet production through molten steel (BOF)	steel	0	0							
Brick/concrete	0	Aggregate	gravel mining/processing	aggregate	0	0							
Total Process Energy							2.84E+08	8.43E+08	1.51E+06	2.42E+08	1.13E+03	1.22E+03	
Total Process MMBtu							2.98E+08	1.18E+06	2.26E+05	2.50E+05	2.82E+04	1.22E+03	4.66E+06

Notes:

[1] Includes diesel oil and gasoline